CONSULTANT REPORT

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CALIFORNIA ENERGY COMMISSION

Energy-Related
Environment Research

COMMERCIAL KITCHEN VENTILATION AND EMISSIONS

Gray Davis, *Governor*

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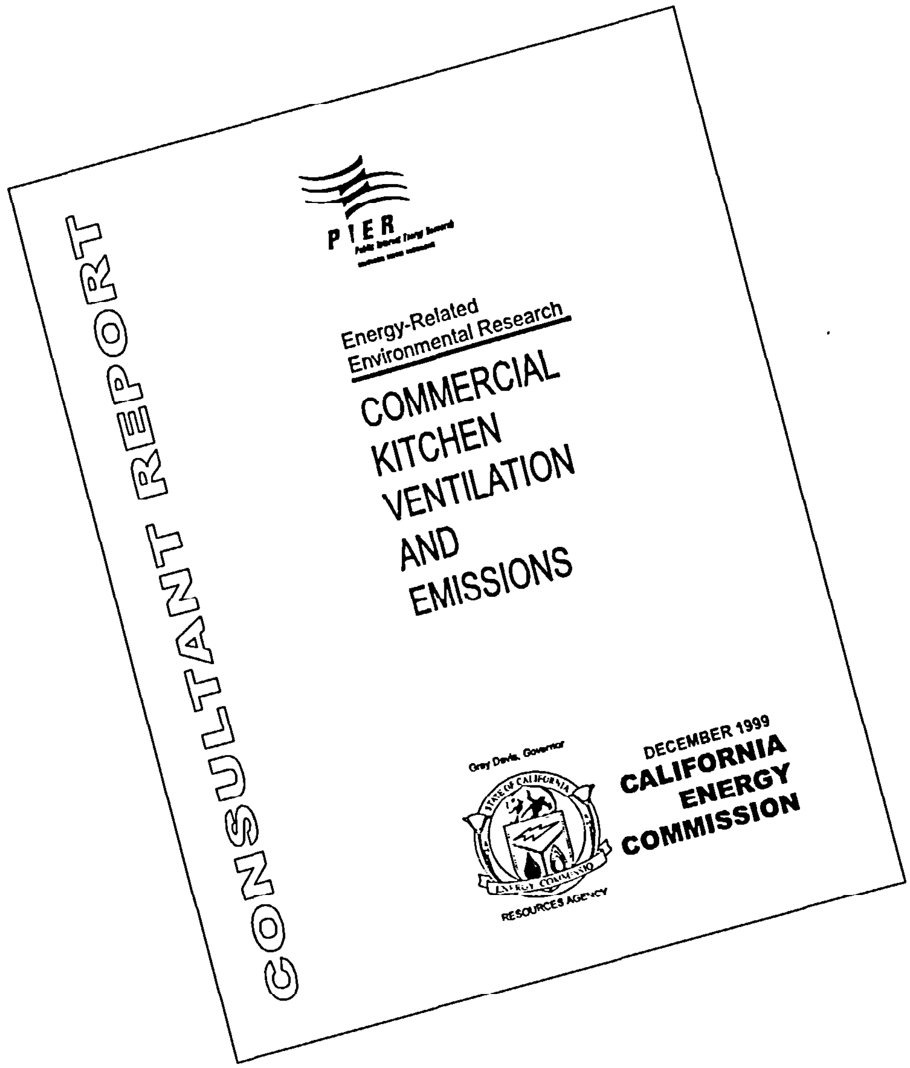

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The establishment of a Food Service Technology Center (FSTC) reflects Pacific Gas and Electric (PG&E) Company's commitment to the food service industry. The goal of the research program is to provide PG&E's customers with information to help them evaluate technically innovative food service equipment and systems and make informed equipment purchases regarding advanced technologies and energy sources. The project was the result of many people and departments working together within PG&E and the support of the commercial equipment manufacturers who supplied appliances for testing.

PG&E's FSTC is supported by its National Advisory Board, which includes:

California Café Restaurant Corporation
California Energy Commission (CEC)
California Restaurant Association (CRA)
Darden Restaurants, Inc.
Electric Power Research Institute (EPRI)
Enbridge / Consumer Gas
Gas Appliance Manufacturers Association (GAMA)
Gas Research Institute (GRI)
International Facility Management Association (IFMA)
McDonald's Corporation
National Restaurant Association
Round Table Pizza
Safeway, Inc.
Underwriters Laboratories (UL)
University of California, Berkeley (UC Berkeley)
University of California, Riverside (CE-CERT)

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million through the Year 2001 to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

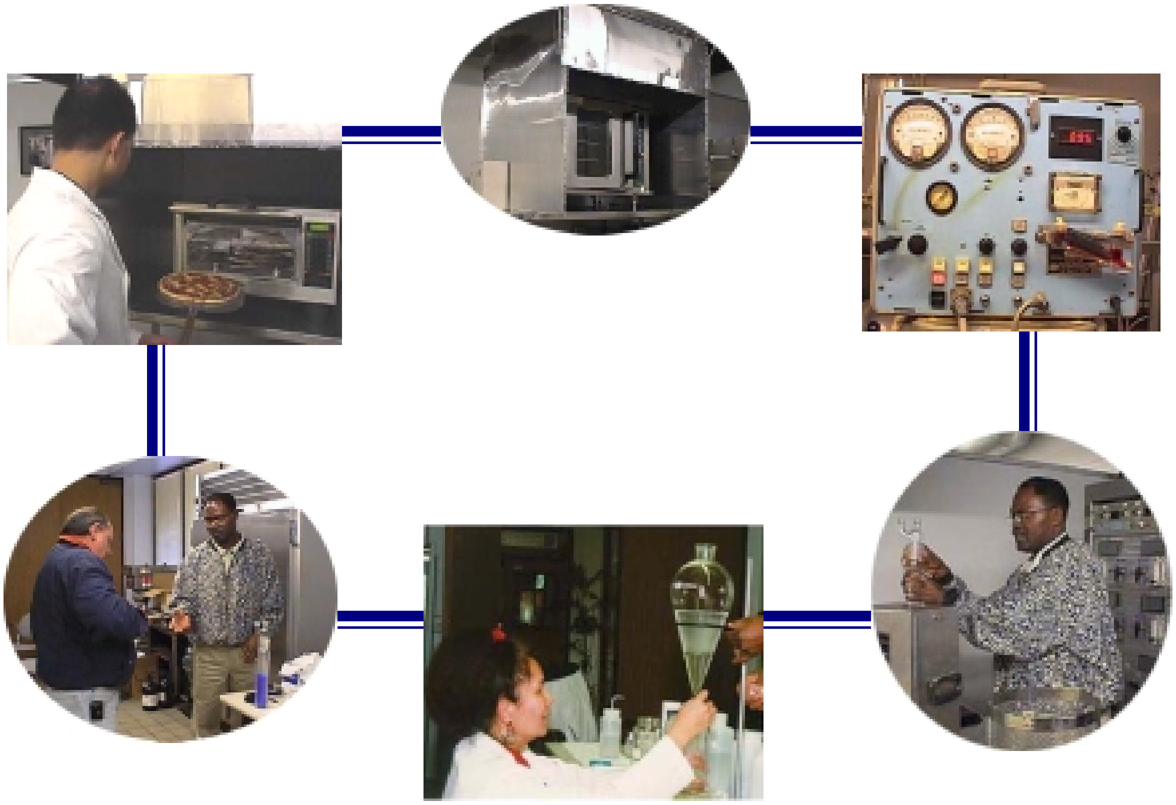
PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

In 1998, the Commission awarded approximately $17 million to 39 separate transition RD&D projects covering the five PIER subject areas. These projects were selected to preserve the benefits of the most promising ongoing public interest RD&D efforts conducted by investor-owned utilities prior to the onset of electricity restructuring.

What follows is the final report for the Commercial Kitchen Ventilation and Emissions project, one of nine projects conducted by Pacific Gas and Electric Company. This project contributes to the Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.



Executive Summary

Food service facilities are the most intensive energy users in the commercial building sector. Typical annual energy consumption for a restaurant operation was reported at 550 kilo British thermal units (kBtu) per foot^2 compared with 100 kBtu / ft^2 for other commercial sub-sectors (e.g., offices, retail, schools, and lodging). The annual energy bill for the food service industry in the United States is estimated at $12 billion.

Commercial kitchen ventilation (CKV) systems significantly impact the energy consumption of food service facilities. It has been demonstrated that the heating, ventilation, and air conditioning (HVAC) load represents approximately 30 percent of the total energy consumed in a restaurant. Further, the kitchen ventilation system can account for up to 75 percent (Fisher 1986) of the HVAC load, and as such, may represent the largest single-system energy consumer in food service operations. However, commercial kitchen ventilation systems are typically designed, installed and operated with little consideration for energy efficiency. This can be attributed to the fact that while designers are primarily concerned with the capability of the CKV systems to capture, contain and remove cooking contaminants, the building owner's goal is to minimize both the design and installed cost of the HVAC system.

This project consisted of two tasks: Commercial Cooking Equipment Emissions Measurement and Control and CKV System Performance Evaluation and Optimization. The overall objective of this transition Public Interest Energy Research (PIER) project was to complete the build-out and commissioning of a kitchen ventilation and a cooking emission test facility. Pacific Gas and

Electric (PG&E) Food Service Technology Center (FSTC) initiated the facility prior to the transfer of utility-managed R&D funding to the PIER program.

Commercial Cooking Equipment Emissions Measurement and Control

The challenge in characterizing emissions generated by commercial cooking equipment is in understanding the nature of the particulate matter (PM) and condensable gases produced. Because of the complicated and transient nature of emissions formation during the cooking process, there is no clear distinction between the components. During cooking, a mixture of solid, liquid, and gaseous substances is emitted. These substances include water and grease in the liquid and vapor phases, non-condensable gases, and solid organic matter.

The American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) funded a study conducted by the University of Minnesota to identify and characterize emissions from various cooking appliance and processes (Gerstler 1998). The South Coast Air Quality Management District (SCAQMD) sponsored a second study in which the College of Engineering—Center for Environmental Research and Technology (CE-CERT) investigated cooking emissions in the exhaust system as they would be released into the atmosphere (Welch 1998).

Until recently, California State law did not require particulate emissions controls on CKV equipment, allowing uncontrolled and unspecified amounts of grease and other particulate matter (PM) to be released into the atmosphere by restaurants. In November 1997, SCAQMD implemented a new regulation (Rule 1138, Appendix VI) affecting emissions of PM and reactive organic gases from conveyorized (chain) broilers. Other California air quality management districts are expected to follow. The basic premise is that air quality will improve with effective methods to measure and control PM.

Objectives

The ultimate goal is to control PM and vapor released from commercial cooking processes through the development of cost-effective emissions control strategies and grease removal devices. The specific task objective was to:

- Investigate and identify methods to measure commercial cooking particulates released to the atmosphere or directly into the kitchen environment by:
  - Developing and testing an emissions measurement test cell.
  - Characterization of emissions for cooking processes potentially not requiring a hood.
  - Developing a Standard Test Method (STM) to measure PM from commercial cooking.
  - Disseminating results to a target audience.

Outcomes

- The build-out of an emissions measurement test cell and associated instrumentation was successfully completed.
- Characterization of emissions from cooking processes focused on light-duty countertop ovens — a half-size bakery oven, a halogen lamp oven, and a high performance hybrid oven.
  - PM emission factors for baking pepperoni pizzas ranged from 0.73 lb. of emissions per 1000 lb. of food cooked for the hybrid oven to 0.22 lb. emissions per 1000 lb. for the halogen lamp oven.
  - Use of a catalytic filter reduced the PM emissions of the hybrid oven by 30 percent (from 0.44 lb. to 0.31 lb. of emissions per 1000 lb. food cooked).
  - Unlike charbroiling and girdling where smoke and grease particles are a dominant component, the majority of PM produced during baking, especially in products high in butter and fat, are condensable grease vapors.
- A STM to measure PM from commercial cooking was derived from SCAQMD Modified Method 5.1, EPA Method 17 and EPA Method 202.
  - Presently, the draft STM is undergoing peer review for ratification as an ASTM test method.
  - The adoption process has been expanded to include national code authorities—Underwriters Laboratories (UL) and the National Fire Protection Agency (NFPA) that use this test protocol for equipment certification.
  - Within this context, the FSTC expanded its testing capabilities and established itself as one of several research centers in North America capable of characterizing the emissions produced by commercial cooking processes.
- The FSTC hosted a commercial cooking equipment seminar: *Practical Limits in Emissions and Odor Control* at PG&E's Energy Center in San Francisco on February 22, 1999.

Conclusions and Recommendations

The threshold values for PM including condensable grease vapor, from discrete cooking appliances or from recirculating hood systems should be defined using an emission rate (i.e., pounds of PM produced per hour) or emission factor (pounds of PM produced per 1000 pounds of food cooked). Currently, underwriter's laboratory (UL) 197 specifies a PM concentration (e.g., 5 mg/m^3) independent of airflow rate. Data from this project suggest that this threshold PM production should be less than 0.01 lb./h per appliance. Applying this to recirculating hoods, the minimum PM emitted into kitchen space should be less than 0.005 lb./h per linear foot of hood.

Significantly more research is needed in this area to ratify such criteria for when an appliance does not need a hood and when a recirculating hood and appliance system is acceptable from both a fire safety and an indoor air quality perspective.

Commercial Kitchen Ventilation (CKV) System Performance Evaluation

Although the opportunities for energy conservation and load management in CKV are large, the lack of publicly documented lab and field data has made achieving such savings difficult. Based on a survey of CKV equipment manufacturers and recently published data, total kitchen ventilation exhaust in the United States appears to be in the range of 2.5 to 3.0 billion cubic feet per minute (cfm).

Initial research demonstrated a potential for significant energy savings by reducing net exhaust. For example, current building code dictates exhaust hood face velocities of 100 to 150 feet per minute (fpm), but levels as low as 50 to 75 fpm have been shown to be satisfactory. ASHRAE published an experimental study that reported only 40 to 50 percent of the normal design flow for wall and island canopies was required to provide satisfactory capture of smoke generated at any location on or beside cooking surfaces.

Recent research at the Pacific Gas & Electric's (PG&E) Food Service Technology Center (FSTC) CKV Laboratory demonstrated that relatively simple design changes provided consistent reductions (20 to 50 percent) across different styles of exhaust hoods. Total estimated savings average between 20 and 30 percent, with savings at some facilities going as high as 60 percent.

Objectives

PG&E constructed an advanced research and demonstration test cell for kitchen ventilation at its FSTC in San Ramon, California to research issues posed by the California restaurant industry and to serve as a hands-on demonstration center for kitchen designers, mechanical engineers, contractors, architects, and food service facility operators.

Objectives were to:

- Upgrade an existing calorimeter test cell to permit measurements to support heat gain calculations from appliances under different hood styles.
- Add a sophisticated air flow visualization system to research and demonstrate exhaust hood performance.
- Install an Air Flow Measurement System for the Ventilation (Calorimeter) Test Cell
- Prepare an introductory design guide.
- Complete the development of an outdoor air load (heating, cooling, and fan energy) software package (Outdoor Air load Calculator).
- Present a workshop for kitchen designers, mechanical engineers, contractors, architects, and food service facility operators.

Outcomes

- Successfully installed a heat gain measurement station in an existing calorimeter test cell.
- Commissioned an airflow visualization system, consisting of a focusing schlieren optical train supplemented with a theater fog generator.
  - Improved system by adding a color digital video camera.
- Successfully installed an airflow measurement system in an existing calorimeter test cell.

- Prepared a design guideline for commercial kitchen ventilation systems.
- Enhanced the Outdoor Airload Calculator to include dehumidification, equipment lockout, and a fan energy calculator.
- Held a one-day workshop for kitchen designers, engineers, architects, and food service operators to present the latest research.

Conclusions and Recommendations

- The new laboratory equipment will allow the Food Service Technology Center to research issues posed by the California restaurant industry and to serve as a hands-on demonstration center for kitchen designers, mechanical engineers and contractors, architects, and food service facility operators.
- The focusing schlieren system is a major breakthrough for visualizing thermal and effluent plumes from hot and cold processes.
  - Allows the documentation of dynamic airflow patterns on videotape.
- The Outdoor Airload Calculator will not only benefit kitchen designers and mechanical engineers and contractors, but to food service facility operators as well. The tool quickly and accurately estimates heating and cooling loads for a building, based on location. Designers can use the tool to size equipment and food service operators can use it to project energy savings for different heating and cooling setpoints.
- The workshop on commercial kitchen ventilation was well received. Participant feedback reinforced the need for continued commercial kitchen ventilation research and transfer of the information to the industry

Further research focusing on how the introduction of replacement (makeup) air affects the energy performance of commercial food service ventilation equipment was recommended and is being funded through a subsequent PIER project. This future research will focus on improving the energy efficiency of commercial kitchen ventilation systems by performing flow-visualization research and publishing design guidelines for the food service community.

Benefits to California

The California Restaurant Association estimates there are more than 70,000 food service operations in California (about 10 percent of the national total). Based on a survey of CKV equipment manufacturers and recently published data, total kitchen ventilation exhaust in the United States appears to be in the range of 2.5 to 3.0 billion cfm.

This project (and subsequent research conducted by the Food Service Technology Center as a result of the testing capabilities established by the project) will benefit California by reducing particulates released to the atmosphere and kitchen environment by commercial cooking equipment. The project will benefit the state by developing a published method to measure commercial cooking equipment particulates. The project will also benefit utility ratepayers by reducing the amount of energy consumed by ventilation hoods and emissions control systems.

It is anticipated that the funds expended on this project will serve the citizens of California over at least the next ten years by providing hands-on information and knowledge regarding CKV systems. The outcome should be a net reduction in energy used for commercial kitchen ventilation.

Abstract

This project consisted of two tasks: Commercial Cooking Equipment Emissions Measurement and Control and Commercial Kitchen Ventilation (CKV) System Performance Evaluation and Optimization. The overall objective of this transition Public Interest Energy Research (PIER) project was to complete the build-out and commissioning of a kitchen ventilation and a cooking emission test facility. Pacific Gas and Electric (PG&E) Food Service Technology Center (FSTC) initiated the facility prior to the transfer of utility-managed R&D funding to the PIER program.

Commercial Cooking Equipment Emissions Measurement & Control—investigated and identified methods to measure commercial cooking particulates introduced into the exhaust hoods and released to the atmosphere, or directly into the kitchen environment by unhooded appliances or recirculating hood systems. This work provides the tools to control particulates and vapor released from commercial cooking processes through development of cost-effective effluent control strategies and grease removal devices.

The objectives of commercial cooking emissions portion of the Project were to:

- Construct a test cell for particulate measurement,
- Apply the particulate measurement protocol to several “unhooded” light -duty appliances, including an oven with an integral grease filtration system,
- Develop a cooking emissions-specific, particulate measurement protocol for ratification as an ASTM Standard Test Method, and
- Sponsor a seminar on commercial kitchen emissions and control.

Commercial Kitchen Ventilation System Performance Evaluation and Optimization—completed an advanced research and demonstration facility for kitchen ventilation at the FSTC laboratory in San Ramon, California. This new laboratory equipment can be used to research issues posed by the California restaurant industry and serve as a hands-on demonstration center for kitchen designers, mechanical engineers and contractors, architects, and food service facility operators.

The objectives of commercial kitchen ventilation portion of the Project were to:

- Upgrade an existing test cell to permit measurements to support heat gain calculations from appliances under different styles of hoods,
- Add a sophisticated air flow visualization system for research and demonstrations of exhaust hood performance,
- Prepare an introductory design guide
- Complete development of an outdoor air load (heating, cooling and fan energy) software package called the Outdoor Airload Calculator, and
- Present a workshop for kitchen designers, mechanical engineers and contractors, architects, and food service facility operators.

The results from this California Energy Commission transition PIER Project (and subsequent research conducted by the FSTC using testing capabilities established by this project) will benefit the public by reducing the particulates released into the atmosphere and kitchen

environment and the energy used for commercial kitchen ventilation. Until recently, the laws did not require particulate emissions controls on commercial kitchen ventilation equipment, allowing uncontrolled and unspecified amounts of grease and other particulate matter to be released into the atmosphere by commercial restaurants. The adoption of Rule 1138 by the South Coast Air Quality Management District (SCAQMD) regulating the release of particulate matter and reactive organic gases from restaurants sets the stage for a new era in cooking equipment emission control. It is expected that other California air quality management districts will follow. Ultimately, air quality (indoor and outdoor) will be improved with effective methods to measure and control particulates produced by commercial cooking processes.

It is anticipated that the funds expended on this project will serve the citizens of California over at least the next 10 years by providing hands-on information and knowledge regarding cooking emissions and CKV systems. The outcome should be a net reduction in energy used for commercial kitchen ventilation.

1.0 Introduction

The California Restaurant Association estimates there are more than 70,000 food service operations in California (about 10 percent of the national total). Based on a survey of Commercial kitchen ventilation (CKV) equipment manufacturers and recently published data, total kitchen ventilation exhaust in the United States appears to be in the range of 2.5 to 3.0 billion cfm.

Food service establishments are the most intensive energy users in the commercial building sector. (EPRI 1988) Typical annual energy consumption for restaurant operations was reported at 550 $kBtu/ft^2$ compared with 100 $kBtu/ft^2$ for other commercial sub-sectors (e.g., offices, retail, schools, lodging). The annual energy bill for the food service industry in the U.S. is estimated at $12 billion.

The CKV systems have a significant impact on the energy consumption of food service facilities. It has been demonstrated (Claar 1985)that the heating, ventilation, and air conditioning (HVAC) load represents approximately 30 percent of the energy consumed in a restaurant (Figure 1). The kitchen ventilation system has been further estimated (Claar 1985) to account for up to 75 percent of the HVAC load, and as such, may represent the largest single-system energy consumer in food service operations. However, CKV systems are typically designed, installed, and operated with little consideration of their energy efficiency. This can be attributed to the fact that designers are primarily concerned with the capability of the CKV systems to capture, contain and remove cooking contaminants, while the building owner's goal is to minimize both the design and installed cost of the HVAC system.

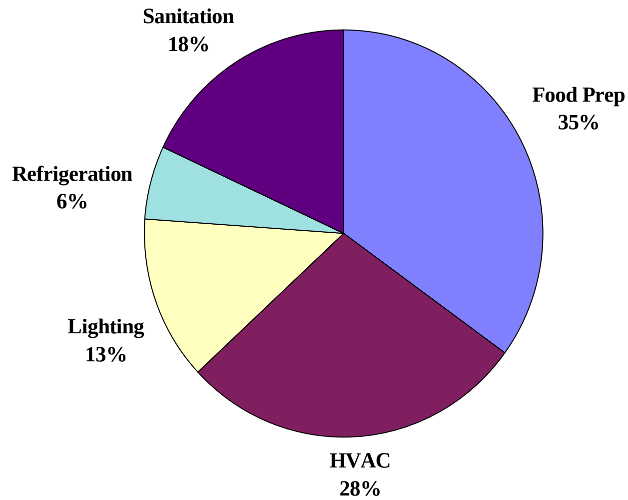


Figure 1. Representative Breakdown of Energy End-Use in a Food Service Operation

1.1 Project Objective

This project consisted of two tasks: Commercial Cooking Equipment Emissions Measurement and Control and Commercial Kitchen Ventilation (CKV) System Performance Evaluation and Optimization. The overall objective of this transition Public Interest Energy Research (PIER) project was to complete the build-out and commissioning of a kitchen ventilation and a cooking emission test facility. Pacific Gas and Electric (PG&E) Food Service Technology Center (FSTC) initiated the facility prior to the transfer of utility-managed R&D funding to the PIER program.

1.2 Report Organization

This project consists of two major sections:

- Section 2 — Commercial Cooking Equipment Emissions Measurement and Control
- Section 3 — Commercial Kitchen Ventilation System Performance Evaluation and Optimization

Section 5.0 contains a glossary of terms and Section 6.0, a list of references.

There are eight appendices:

Appendix I:	Example Source Test Data and Calculations
Appendix II:	Draft Standard Test Method
Appendix III:	FSTC National Advisory Board Meeting #27 Presentation
Appendix IV:	FSTC National Advisory Board Meeting #28 Presentation
Appendix V:	Emission Workshop Agenda and Presentations
Appendix VI:	SCAQMD Rule 1138, Control of Emissions from Restaurant Operations
Appendix VII:	Commercial Kitchen ventilation Seminar Flyer and Agenda
Appendix VIII:	Commercial Kitchen Ventilation Guideline for California

2.0 Commercial Cooking Equipment Emissions Measurement and Control

2.1 Emissions Characterization for Commercial Cooking

The challenge in characterizing emissions generated by commercial cooking appliances is understanding the nature of the particulate matter (PM) and condensable gases being produced. Due to the complicated and transient nature of emissions formation, there isn't a clear distinction between the components.

During cooking, a mixture of solid, liquid and gaseous substances is emitted. These substances include water and grease in the liquid and vapor phases, non-condensable gases, and solid organic matter. The condensation of grease and water vapor in the air stream and on the ventilation equipment depends on a number of factors, including the temperature of the gas and surrounding surfaces, vapor pressure, and the concentration of the vapors.

In addition, solid particulates and grease droplets are entrained into the thermal plume as grease and water explode during the cooking process. Other complications arise from the transient nature of the cooking process. Because of these physical traits, results are highly dependent on the capture and characterization methods as well as the cooking methods involved. (Gerstler 1998).

Only recently has there been a better understanding of the nature of emissions generated by commercial cooking and the impact of ventilation and emission control systems. There have been two significant research contributions within the last few years. The American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) funded a study conducted by the University of Minnesota to identify and characterize emissions from various cooking appliance and processes (Gerstler 1998). In a second study, sponsored by the South Coast Air Quality Management District (SCAQMD), the College of Engineering—Center for Environmental Research and Technology (CE-CERT) investigated cooking emissions in the exhaust system as it would be released into the atmosphere (Welch 1998).

2.2 Variations in Test Procedure

There are a number of methods currently available that characterize PM emissions from stack emissions. The U. S. Environmental Protection Agency (EPA) Method 5 is the basis for most of these methods. Because none are designed specifically for cooking emissions, testing facilities have modified them, leading to several variations in test methods. As a result, comparison of data can be difficult. In 1997, AGAResearch attempted to develop a grease extraction protocol specifically for commercial kitchen emissions under ASHRAE RP-851 "Grease Extraction and Removal From Exhaust Air Streams of Cooking Processes" (Schlock 1997). The project did not produce a functional test protocol.

Recently, the need for a standard has been accelerated since air quality districts have begun to impose regulations limiting restaurant emissions. In November of 1997, the South Coast Air Quality Management District (SCAQMD) adopted Rule 1138 that required chain-driven charbroilers to be equipped with emission control equipment (SCAQMD 1997).

SCAQMD is currently researching additional control technologies to reduce emissions from under-fired charbroiling processes. The rule will be expanded to include other cooking processes when economically viable control technologies are made available. Ultimately, it is expected that other air districts will follow adoption of similar regulations. It is important that a standardized test method to measure grease from cooking emissions be developed to oversee the adopting process.

2.3 Criteria for Ventilation

In indoor air quality, there is a tug-of-war between restaurant operators and code authorities on the issue of ventilation; specifically when is a hood not required. If a hood is required, when is a Type I hood (for grease laden air) not required?

There exists a category of light-duty low emission electric appliances (e.g., specialized countertop ovens) that may not need a hood or need to be vented by either a Type I grease hood or a Type II vapor hood. Ventilation requirements for cooking emissions in commercial kitchens vary from county to county. Federal regulatory bodies, such as the Occupational Safety and Health Administration (OSHA), Underwriters Laboratories (UL) and the National Fire Protection Agency (NFPA), delineate minimum health and safety requirements, but local jurisdictions can either meet or exceed these guidelines. As a result, a kitchen ventilation design may meet local codes in one jurisdiction, but fail to meet requirements in others.

There is no specific test protocol to determine whether a hood is required or not. However, a surrogate test method exists for evaluating the performance of recirculating (ductless) hood / appliance systems. UL 197—"Standard for Commercial Electric Cooking Appliances" imposes a pass or fail criteria for ductless hoods, one of which is an emissions test for cooking appliances (Underwriters Laboratory 1996). The concentration criterion set at 5 mg/m^3 employs EPA Method 202 for sampling grease-laden emissions to determine condensable grease vapor. It is implied then, that if a recirculating appliance / hood combination is acceptable below 5 mg/m^3, then an appliance without a hood that produces the same amount of emissions should be permitted. But the code is vague, leaving room for interpretation.

Employing concentration values to evaluate an upper limit in emissions generation is misleading when applied to commercial cooking processes with ventilation. Concentration is defined as the amount of matter within a given volume. If the amount of matter or volume is changed, the concentration changes. With ventilated emissions, simply increasing the ventilation rate can dilute PM concentrations. For instance, a recirculating hood / appliance generating 8 mg/m^3 PM emissions at 500 cfm can theoretically be reduced to 4 mg/m^3 just by increasing the ventilation rate to 1000 cfm. The appliance fails the UL requirement of 5 mg/m^3 at 500 cfm, but passes at 1000 cfm. Yet the same amount of grease is introduced into the kitchen environment. Such discrepancies are easily overlooked because the code does not spell out an absolute threshold for grease emissions in pounds per hour (emission rate) or pounds per 1000 pounds of food cooked (emission factor).

2.4 Objective and Scope

Commercial Cooking Equipment Emissions Measurement and Control—investigated and identified methods to measure commercial cooking particulates introduced into exhaust hoods and released to the atmosphere, or introduced directly into the kitchen environment from unhooded appliances or recirculating hood systems. The ultimate goal was to control particulates and vapor released from commercial cooking processes through development of cost-effective emissions control strategies and grease removal devices.

The specific objective was to:

- Investigate and identify methods to measure commercial cooking particulates released to the atmosphere or directly into the kitchen environment by:
  - Developing and testing an emissions measurement test cell.
  - Characterizing emissions for cooking processes potentially not requiring a hood.
  - Developing a Standard Test Method (STM) to measure PM from commercial cooking.
  - Disseminating results to a target audience.

2.5 Emissions Measurement

To measure commercial cooking particulates released to the atmosphere or directly into the kitchen environment, PG&E installed a particulate measurement sampling train and data collection hardware. It initially focused on the development of an emission factors database for commercial cooking processes such as hamburgers on griddles, shoestring potatoes in a deep-fat fryer, and steak on a charbroiler. Because of real-world manufacturers' and operators' requests, the testing emphasis shifted to countertop appliance emissions.

End-users argued that low emitting appliances should be allowed to operate without a hood, letting general kitchen ventilation remove the emissions. The research provided valuable and timely insights for manufacturers, end-users and code authorities. It required compiling existing test results from various past studies. This report tabulates and presents emission factors established by the University of California, Riverside's CE-CERT and the University of Minnesota.

2.6 Emission Measurement Test Cell

Emission measurements were conducted in a 20′ × 17′ × 11′ test cell equipped with natural gas, electricity, ventilation and fire suppression. Natural gas was accessed through a 1 ¼″ pipe at 7.5 pounds per square inch gauge (psig). Electrical service was available at 115 V single phase and 208 V three phase. Exhaust ventilation was provided by a wall-mounted exhaust hood ducted to a centrifugal-type upblast blower located on the roof above the test room. Make-up air was supplied by a mechanical air-conditioner and two diffusers located in the center of the room.

Figure 2 shows an overview of the emission measurement test cell.

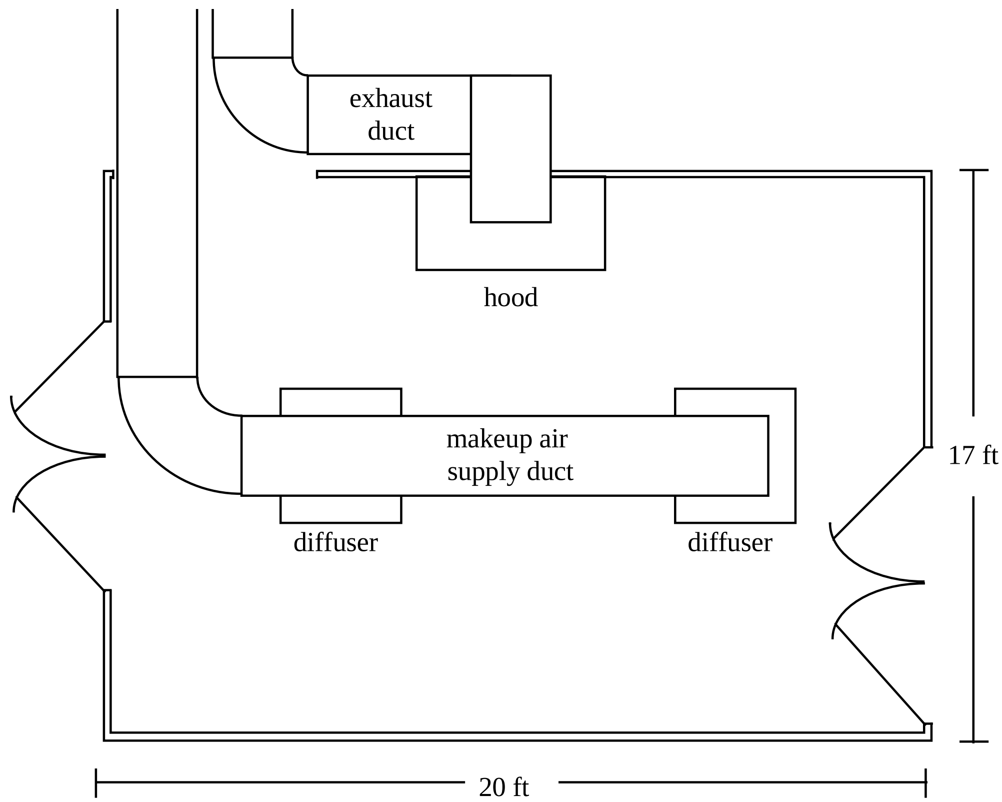


Figure 2. Test Cell Schematic

The natural gas flow rate was measured with a calibrated dry gas meter. The heating value was determined by gas chromatography as outlined by ASTM D3588-95 “Standard Practice for Calculating Heating Value, Compressibility Factor, and Relative Density (Specific Gravity) of Gaseous Fuels.” A Staco voltage regulator maintained the electrical voltage at a constant 208V during testing. A Greenheck 4' x 8' stainless steel, wall-mounted canopy hood was modified to act as a dedicated hood to ensure total capture of the natural convection plume (Figure 3). To accomplish this, the mechanical ventilation rate was set to slightly exceed the natural plume flow rate (approximately 200-cfm).

Figure 3. Canopy Hood Modified to Act as a Natural Convection Receiving Hood

Traverse sampling took place across the 8″ x 8″ square duct opening with the probe nozzle directed upstream. Stainless-steel panels extended the ductwork from the 8″ x 8″ square mouth to the width of the appliance. Side panels affixed to the duct extensions and the back wall provided enclosure to all sides of the oven, except the front face.

To prevent emissions escape during the loading and unloading process from the front face, an additional panel was extended from the hood to the top edge of the appliance, leaving enough room only for opening and closing the oven door (Figure 4).

Adjustments to the side panels were made on an appliance-to-appliance basis and the effectiveness of emissions capture was verified using a fog generator under the test ventilation rate. The exhaust blower was equipped with a variable speed controller to permit flow rate adjustment.

Figure 4. Extended side panels ensure total capture

2.7 Particulate Matter Instrumentation

Figure 5 shows a schematic of the sample impinger train used by FSTC to measure PM emissions. The nozzle assembly (front end) employed a modified version of EPA Method 17. The adjustment required that the filter be placed immediately upstream of the impinger train, instead of in the stack. The back end of the setup followed EPA Method 202 protocol, which was modified by substituting an empty impinger in place of an impinger containing water in the first position of the train (EPA 1991).

The nozzle was placed in the plume facing upstream and traversed over the cooking cycle at equal intervals. The pump isokinetically drew the cooking emissions through an unheated sample probe and a 0.3-micron, glass fiber, filter (99.95 percent efficient), trapping solid PM. The filtered emissions flowed into the impinger train, which was submerged in an ice bath. The first impinger was empty, the second and third impingers contained de-ionized water, and the fourth contained silica gel. The emissions bubbled through the impingers, condensing the grease vapors in the chilled water. The silica gel contained in the fourth impinger removed moisture in the emissions before they entered the pump. A gas meter measured the total volume of emissions sampled.

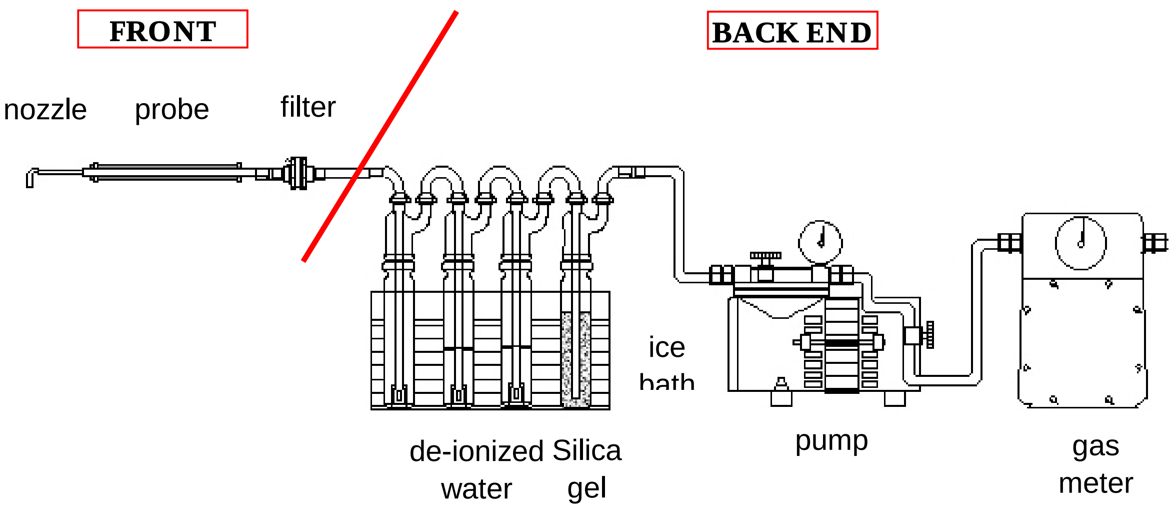


Figure 5. Sampling Train Schematics

2.7.1 Analytical Process

Particulate matter captured by the probe / nozzle assembly and filter were analyzed using EPA Method 17. The filter was desiccated for a 24-hour period or until a constant weight was achieved. The nozzle / probe assembly was brushed and rinsed with acetone to remove all visible particulates (Figure 6). The wash was dried at ambient temperature and pressure under a laboratory hood and desiccated for a 24-hour period or until a constant weight was achieved.

EPA Method 202 analyzes the impinger train solution. Methylene chloride was used as an extraction agent to pull the organic grease condensate from the impinger water (Figure 6). Similar to the acetone wash used for the probe assembly, the organic phase (grease / methylene chloride extract) was dried in ambient temperature under a laboratory hood and weighed to a constant weight. The aqueous phase (impinger water) was reduced by evaporation and dried in a 210°F oven until a constant weight was achieved. The total PM was the combined mass of filter catch, dried organic extract and dried aqueous extract.

Figure 6. Collecting Nozzle/Probe Assembly Rinse

2.7.2 Characterization of Emissions for Cooking Processes Potentially Not Requiring a Hood

The focus on testing equipment was again revised to accommodate an industry need to characterize the emissions produced by light-duty cooking processes. Three different oven manufacturers approached the FSTC to determine if a hood was required for their different oven models. To ascertain that hoods were or were not needed, the FSTC applied EPA Method 202 and UL 197, currently applied to approval of recirculating hood systems.

One of the ovens incorporated an integral air and grease filtering system. FSTC performed an evaluation of this oven with and without the grease removal system to determine the PM removal efficiency of the filtration system. (Note: The revised scope was subsequently endorsed by the FSTC National Advisory Board at its May 1999 meeting.) The alteration to the test plan provided valuable and timely data for manufacturers and end-users and positioned the FSTC to evaluate other grease extraction and removal systems using the emissions measurement test cell now functional within the physical FSTC facility.

2.8 Characteristic Emissions for Appliances Potentially Not Requiring a Hood

2.8.1 Half-Size Bakery Oven

The tested bakery oven (Figure 7) was similar in design to other half-size convection ovens, except the controls are geared toward a specific food product. The 8-kW countertop oven had a stainless-steel exterior measuring 30″ width × 26 ½″ depth × 29″ height. Air was circulated over the heating elements and forced into the oven cavity, measuring 15 ½″ wide × 21 $^{1}/_{8}$″ deep × 20″ high, by a ¼-horsepower fan. Unlike its generic counterparts, the electronic controls are pre-set with four unique programs optimized for defrosting and baking cinnamon rolls. The controls allow a countdown timer for each of the four individual racks.

Figure 7. Half-Size Gas Oven for Baking

2.8.2 Process Condition

Prior to testing, the frozen cinnamon rolls were placed one-inch apart on sheet pans lined with freezer paper. The pans were tightly sealed with plastic wrap and tempered in a refrigerator at 40 ± 2°F for at least 24 hours, but less than 48 hours. The oven was idled for one hour prior to any cooking event. At the end of the idle period, the cinnamon rolls were removed from the refrigerator, placed in the baking pan, sprinkled with toppings and cinnamon, and loaded on to the first (top) rack of the oven. The baking program for cinnamon rolls was initiated for the first rack. A second pan of rolls was prepared and loaded on the next rack, and the cooking event initiated for the second rack.

The time interval between the loading of the first rack and the second rack was exactly one minute. The procedure was repeated for the third and forth racks until the oven was baking at full capacity. The unloading process followed a similar procedure. While the cooked rolls were being removed from each rack, a new pan of rolls was prepared and placed on that rack within the one-minute period (Figure 8). Each full-load batch required 30 minutes to cook, including loading and unloading. The entire test consisted of three full-load batches, totaling 90 minutes. The three-load test was replicated three times, for a total of nine loads and total test time of 270 minutes. The tempering and preparing processes strictly followed the manufacturer’s training guidelines to replicate real-world food handling and to ensure process repeatability.

Figure 8. Baked Cinnamon Rolls From the Half-Size Bakery Oven

2.8.3 Halogen Lamp Oven

The countertop halogen lamp oven (Figure 9) was constructed of a stainless steel exterior, measuring 27 $^{3}/_{8}$″ wide × 28 $^{7}/_{8}$″ deep × 19 ½″ high, and a reflective Ananod interior, measuring 18″ width × 18″ depth × 7 $^{3}/_{4}$″ height. Seven 2000-watt quartz halogen lamps, four on the top and three on the bottom, draw a maximum power output of 11.9 kW. Electronic digital controls allow standard full-light output or a combination of varying intensities for programmed cooking.

Figure 9. Halogen Lamp Oven

2.8.3.1 Process Condition

Test pizzas were assembled to the specifications described in Sections 7.1-7.4 of ASTM designation F1817-97, Standard Test Method for the Performance of Conveyor Ovens (ASTM 1997). Pizza crusts were 12-inches in diameter with a par-baked crust weighing 0.9 ± 0.2 lb. with a moisture content of 36 percent by weight. The pizza sauce was a simple, tomato-based sauce with a moisture content of 86 percent. The cheese was part-skim 50 percent moisture shredded mozzarella cheese. The pepperoni was pre-sliced with a moisture content of three percent. All ingredients were verified for proper moisture content by gravimetric analysis.

The test pizzas were made using the following steps: 0.25 lb. of sauce spread on top of the crust within 0.5 in of the edge, 0.375 lb. of cheese distributed uniformly over the sauce, and 0.10 lb. (twenty-five slices) of pepperoni layered on top of the cheese. Each pizza had an average weight of 1.4 pounds. The pre-made pizzas were placed on sheet pans lined with freezer paper, sealed tightly with plastic wrap and tempered in a refrigerator at 40 ± 2°F for at least 18 hours, but less than 48 hours.

Figure 10. Loading Pepperoni Pizza into the Halogen Lamp Oven

A two-step heating program provided the desired final pizza temperature and the best food quality. The recipe is a two-minute program with an initial 50 seconds step at full intensity and a second step of one minute and ten seconds with light intensities of Top Inner and Top Outer set at 100 percent, Bottom Inner at 40 percent and Bottom Outer at 95 percent.

Each pizza required a cooking time of two minutes and 30 seconds—two minutes for actual cooking, 30 seconds for the loading and unloading processes (Figure 10). An entire test required 24 pizzas for a total testing time of 60 minutes. This 24-load test was replicated three times, for a total of 72 loads and a total test time of 180 minutes.

2.8.4 Hybrid Oven with Integrated Grease Filtration System

The hybrid oven used a combination of microwave and convection technology for cooking. The oven incorporated an integral air and grease filtering system that potentially allows it to operate without an exhaust hood. FSTC evaluated the oven with and without the grease removal system to determine the PM removal efficiency of the filtration system.

2.8.4.1 Process Condition

The test pizzas were assembled to the specifications described in Sections 7.1-7.4 of ASTM designation F1817-97, Standard Test Method for the Performance of Conveyor Ovens, and the procedure for making the pizzas follow the steps as described in Section 2.8.3.1.

Each pizza required a total cook time of 103 seconds—73 seconds for actual cooking, 30 seconds for the loading and unloading processes. An entire test required 35 pizzas with time totaling 60 minutes. FSTC replicated the 35-load test three times, for a total of 105 loads and a total test time of 180 minutes.

Since the hybrid oven had a built-in air and grease filter, two sets of tests were performed to evaluate the emission filtering efficiency.

2.9 PM Emission Outcomes

Table 1 and Figure 10 summarize the total particulate matter concentrations for the cooking processes evaluated within this project. The half-size oven baking cinnamon rolls produced a total PM concentration of 21.0 mg/m^3. The halogen lamp oven cooking pepperoni pizzas emitted 9.3 mg/m^3. Without the catalytic filter, the hybrid oven cooking pepperoni pizzas produced 29.4 mg/m^3, but with the catalytic filter, the emission was 20.4 mg/m^3, a PM reduction of 31 percent. All four appliances were tested under a ventilation rate of 210 cubic feet per minute at standard conditions (scfm).

Table 1. Total Particulate Matter Emission Concentrations.

Appliance	Food Product	Flow Rate (scfm)	Concentration (mg/m^3)
half-size bakery oven	cinnamon rolls	210	21.0
halogen lamp oven	pepperoni pizzas	210	9.3
hybrid oven without filter	pepperoni pizzas	210	29.4
hybrid oven with filter	pepperoni pizzas	210	20.4

ventilation rate = 210 scfm

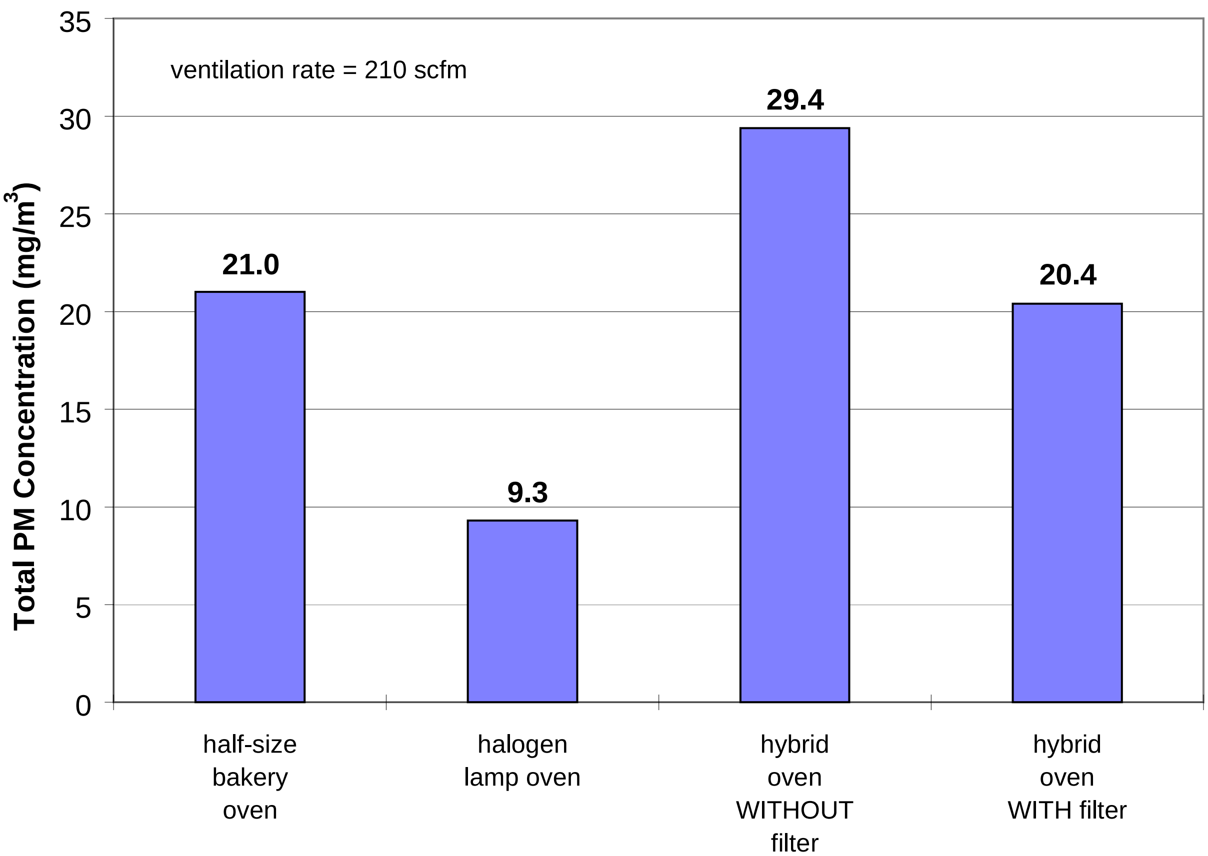


Figure 11. Total Particulate Matter Emission Concentrations

Table 2 and Figure 11 present the emission factors and emission rates, which are independent of the ventilation rate. Under the tested parameters, the half-size bakery oven produced 0.73 lb. PM emissions / 1000 lb. of food cooked, equivalent to 0.017 lb. PM emissions per hour. The halogen lamp oven generated 0.22 lb. of PM emissions per 1000 pounds of food cooked, translating to 0.0053 pounds. PM emissions per hour. Without the filter, the hybrid oven emitted 0.44 lb. PM emissions per 1000 pounds of food cooked or 0.023 lb. emissions per hour. The catalytic filter reduced the emission factor and emission rate to 0.31 lb. PM emissions / 1000 lb. food cooked and 0.016 lb. emissions / h, respectively.

Table 2. Total Particulate Matter Emission Rates and Emission Factors.

Appliance	Food Product	Emission Factor (lb. Emission/1000 lbs Food Cooked)	Emission Rate (lb. Emission/h)
half-size bakery oven	cinnamon rolls	0.73	0.017
halogen lamp oven	pepperoni pizzas	0.22	0.005
hybrid oven WITHOUT filter	pepperoni pizzas	0.44	0.023
hybrid oven WITH filter	pepperoni pizzas	0.31	0.016

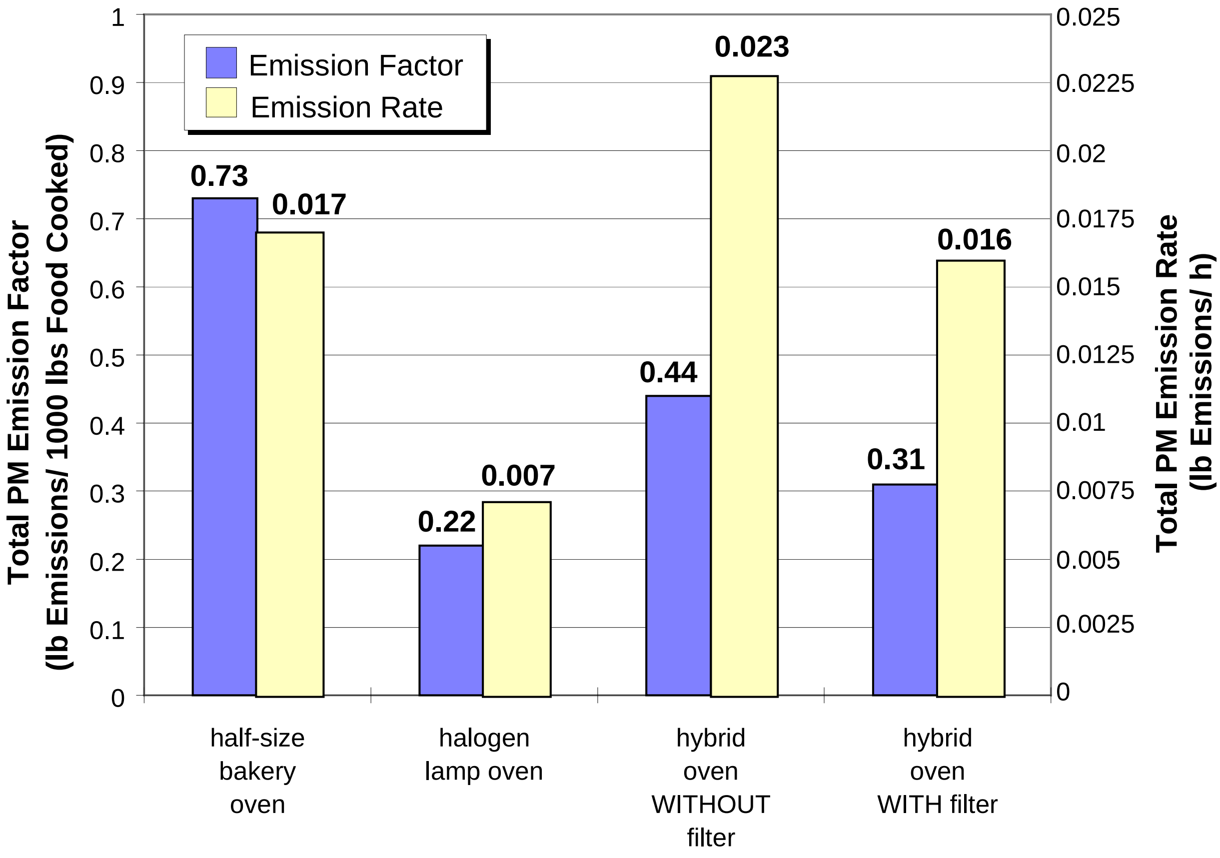


Figure 12. Particulate matter emission factors and emission rates

2.10 Emission Factors of Other Studies

Two recent studies took on the challenge of characterizing emissions from common commercial cooking processes. Sponsored by American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), the University of Minnesota examined the PM emissions in the cooking plume (i.e., before entering the hood filter and exhaust ductwork (Gertsler 1998). In the second study, sponsored by the South Coast Air Quality Management District (SCAQMD), the College of Engineering—Center for Environmental Research and Technology (CE-CERT) investigated cooking emissions in the ventilation ductwork as it would be released into the atmosphere (Welch 1998).

The following sections summarize the characterization of cooking emissions, obtained through published literature and personal contacts, from these two studies. Be advised that no two studies can be compared directly since variations in process parameters, ventilation settings, and food and ambient conditions exist.

2.10.1 University of Minnesota.

University of Minnesota conducted a study characterizing emissions from various grease-laden cooking processes within the natural cooking plume. The appliances evaluated included gas and electric versions of single-sided griddles, open-vat deep-fat fryers, under-fired broilers, full-size convection ovens, and six-burner ranges. Grease particulates and vapor were sampled within the cooking plume, immediately above the appliance, using an inertial impactor followed by an EPA Method 5 condensing train. Measurements include the natural plume velocity and temperature profiles, grease particulate and vapor emissions and dry gas emissions. Additional measurements include real time particle size distributions within the emissions plume and within the exhaust duct. The impactor determined grease particulate size distributions, while the condensable gases were measured using EPA Method 201A.

Table 3 and Figure 13 summarize the emission factors of the University of Minnesota's research project. Particulate size distribution, dry gas emission and test parameters are not included. For further information, refer to ASHRAE report 745-RP: *Identification and Characterization of Emissions from Various Cooking Appliances and Processes as Related to Optimum Design of Kitchen Ventilation Systems*. (Available as a publication from the FSTC).

Table 3. University of Minnesota Reported PM Emission Factors.

Appliance	Rated Input	Food Product	Emission Factor (lb. emission/1000 lb. food cooked)
Gas Griddle	80 kBtu/h	20% fat, frozen, quarter-pound hamburger	16.4
Electric Griddle	10.7 kW (208V)	20% fat, frozen, quarter-pound hamburger	14.9
Gas Fryer	80 kBtu/h	2.2% fat, 70% moisture, par-cooked shoestring potatoes	2.9
Electric Fryer	12.9 kW (208V)	2.2% fat, 70% moisture, par-cooked shoestring potatoes	3.5
Gas Broiler	108 kBtu/h	20% fat, frozen, 62% moisture, 1/3 pound hamburger	50.3
Electric Broiler	10.8 (208V)	20% fat, frozen, 62% moisture, 1/3 pound hamburger	33.4
Gas Broiler	108 kBtu/h	2.7% fat, 74.3% moisture, skinless boneless chicken breast	13.9
Electric Broiler	10.8 (208V)	2.7% fat, 74.3% moisture, skinless boneless chicken breast	11.7
Gas Oven	55 kBtu/h	8.2% fat, 53.5% moisture, sausage pizza	1.3
Electric Oven	11 kW (208V)	8.2% fat, 53.5% moisture, sausage pizza	2.7
Gas Range	120 kBtu/h	spaghetti with pork sausage	6.7
Electric Range	12 kW (208V)	spaghetti with pork sausage	4.3

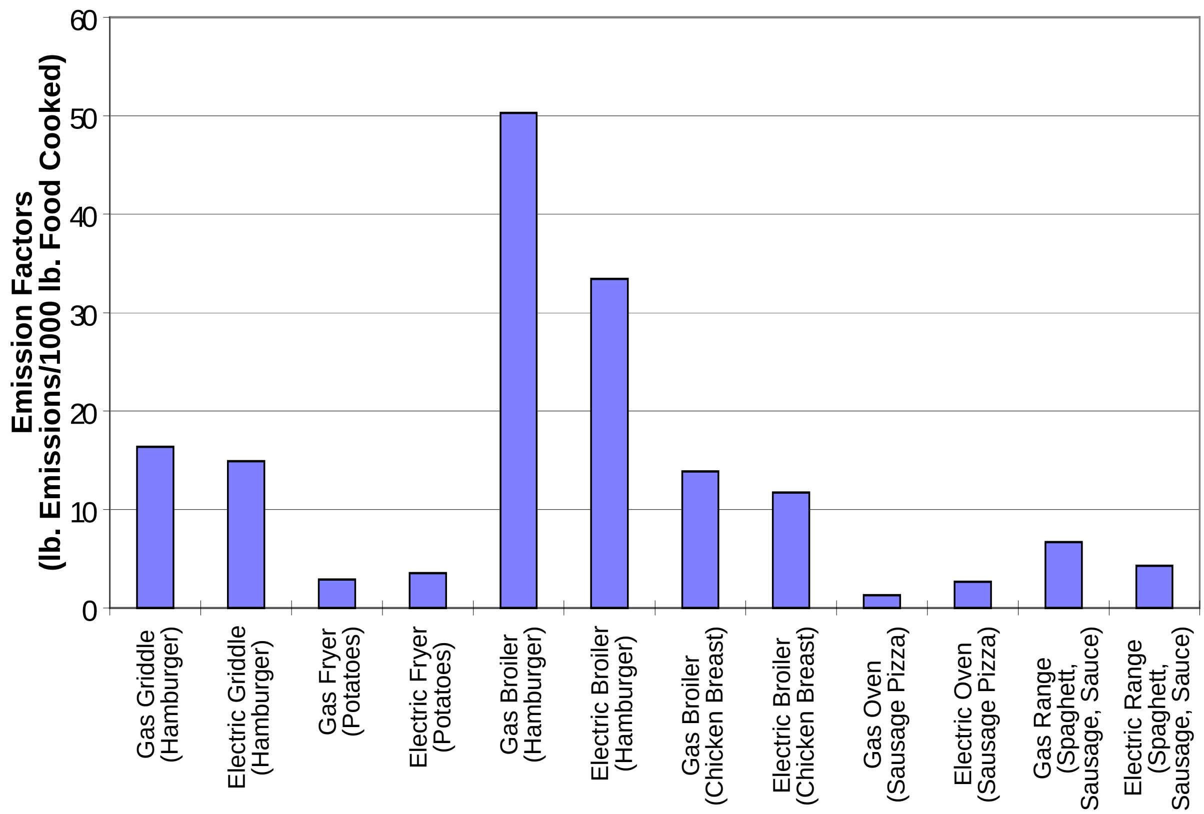


Figure 13. University of Minnesota PM emission factors.

2.10.2 University of California, Riverside

The University of California at Riverside's College of Engineering—Center for Environmental Research and Technology (CE-CERT) conducted a study aimed at quantifying and reducing outdoor air pollution from restaurant emission, "Development of Emission Test Methods and Emission Factors for Various Commercial Cooking Operations." The program's objectives were to produce more reliable and reproducible protocols for the sampling and analysis of volatile organic compounds (VOC) and PM emissions from commercial cooking operations, and apply them to generate a database of emission factors. The PM test procedures included the characterization of particle size distributions using an inertial impactor. CE-CERT used the new protocols to evaluate emission factors from eighteen commercial cooking processes, including five processes using emission control technologies. Appliances tested included an under-fired charbroiler, a griddle, a chain-driven charbroiler and a deep-fat fryer.

Unlike the in-plume sampling performed by the University of Minnesota, CE-CERT's sampling ports were located in the ventilation ductwork. Emissions were sampled ten duct diameters downstream from any flow disturbance through an unheated, stainless-steel probe, impingement train immersed in an ice bath, and 0.45 µm quartz fiber filter. Sample analysis was performed according to modified SCAQMD Method 5.1.

Table 5 and Figure 14 summarize the emission factors determined by CE-CERT's test program. Particulate size distributions, VOC data, emission control technology efficiencies and numerous test parameters are not included in this report. Further information can be obtained in the cited reference (Welch 1998).

Table 4. CE-CERT Reported PM Emission Factors.

Appliance	Rated Input	Food Product	Emission Factor (lb. emission/1000 lb. food cooked)
Gas Charbroiler	87 kBtu/h	20% fat frozen hamburger	32.7
Gas Charbroiler	87 kBtu/h	New York steak	17.2
Gas Charbroiler	87 kBtu/h	whole chicken, butterfiled	10.5
Gas Charbroiler	87 kBtu/h	Atlantic salmon	3.3
Electric Griddle	13.3 kW	24% fat frozen hamburger	5.0
Electric Griddle	13.3 kW	skinless/boneless chicken breast	BDL
Electric Griddle	13.3 kW	cod fillet	BDL
Electric Griddle Double-Sided	13.3 kW	24% fat frozen hamburger	0.9
Gas Fryer	43 kBtu/h	1/4" shoestring french fries	BDL
Gas Fryer	22 kBtu/h	3 oz. breaded chicken patties	BDL
Gas Fryer	22 kBtu/h	4 oz. breaded cod fillet	BDL
Gas Chain-Driven Charbroiler	NA	21% fat hamburger	7.4

BDL = Below Detectable Limits

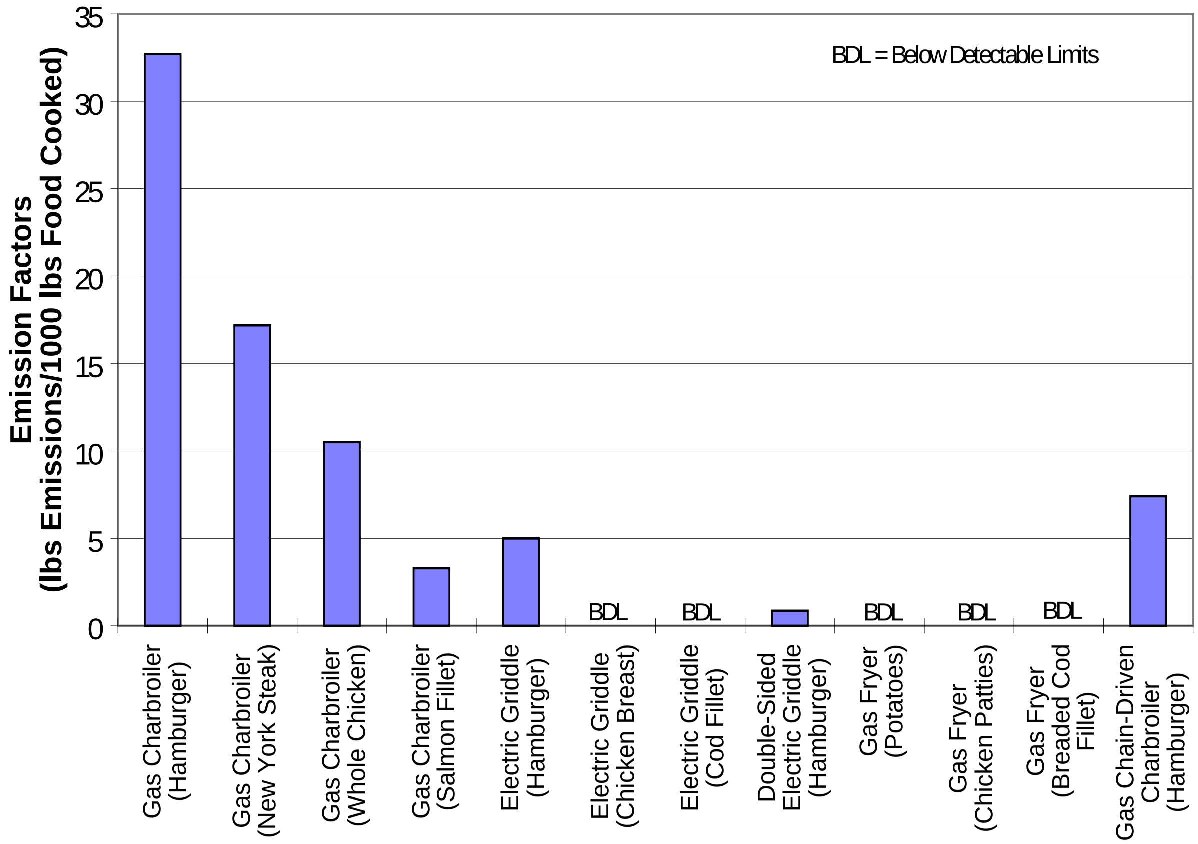


Figure 14. CE-CERT PM emission factors.

2.11 Standardized Test Method (ASTM) Development

2.11.1 Secure and Ratify Emission Protocol as an ASTM Standard

The task required a literature review of existing test methods for measuring PM emissions and a proposal of a more effective protocol for cooking emissions. The South Coast Air Quality Management District's (SCAQMD) Modified Method 5.1 and Environmental Protection Agency's (EPA) Method 5 derivatives was further developed into an ASTM Standard Test Method.

2.11.2 FSTC National Advisory Board Meeting Presentation

A summary of the California Energy Commission's Transition PIER Project was presented at the FSTC's 27th National Advisory Meeting in May 1999 (Appendix III). The draft Emission STM was made available and the group discussed its technical merit and the ensuing ASTM reviewing process.

The advisors expressed concern with the pace of the test method development. A new standard could jeopardize the validity of existing methods. For example, it was suggested that equipment, which was already certified by UL and NFPA, could be forced to undergo a new round of testing with the advent of an ASTM standard. The Board suggested the FSTC work with these two organizations before approaching ASTM. The strategy now is to solicit involvement from research labs and commercial kitchen ventilation manufacturers. The draft emission STM, currently in the peer-preview process, is available as a working document from the Food Service Technology Center and is included in Appendix VIII.

The following sections highlight the presentation and the discussion that followed.

2.11.2.1 Modifications to Existing Test Methods

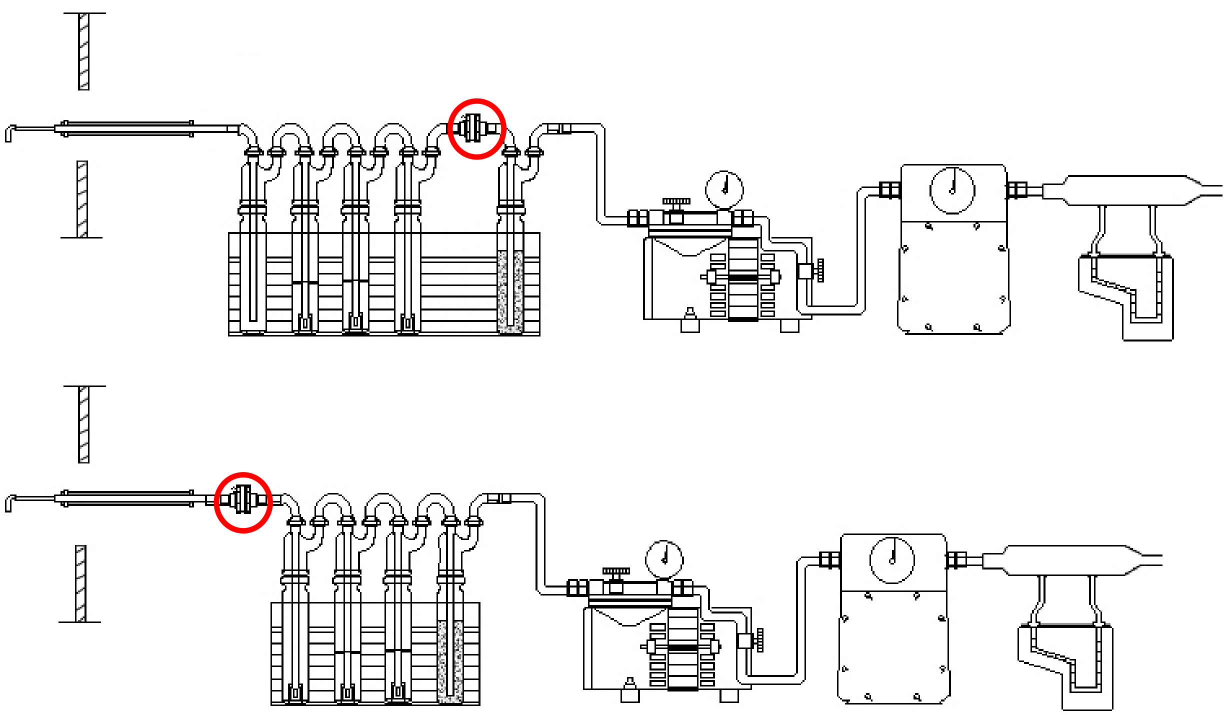
1. Title Change—The proposed Emission STM draft is titled "Standard Test Method for Determining Particulate Matter and Condensable Gas Emissions from Commercial Cooking Processes." The title change is cosmetic, but it does point out several defining points. The EPA Method 5 and the SCAQMD modified Method 5.1 are general in application and can be applied to all "stationary sources." By narrowing the application to "commercial cooking processes," irrelevant procedures can be omitted, while useful analysis can be added. By EPA's and SCAQMD's definition, condensable gases are a sub-category of particulate matter emissions. By including "condensable gas" in the title, it brings into light the importance of grease vapor in cooking emissions. Industrial combustion processes such as coal-burning plants typically generate large particles such as fly ash and chemical derivatives such as sulfates, acids and halides with little or no condensable grease vapors. The emissions from cooking processes are typically lower in concentrations, and comprised largely of grease and smoke particles and condensable (grease) vapor. In some cases, the condensable vapor represents the dominant component of the total particulate matter emission.

2. Analysis Removal—The sulfate and acid analysis found in some protocols are geared toward coal-burning power plants and chemical processes. Cooking emissions do not typically contain such components. By removing unnecessary procedures, the cost of analysis is reduced.

3. Additional Procedure—Measuring and reporting particulate size distribution adds information that is valuable for hood and filter design. Currently, there are two types of commercially available impactors.

4. Calibration Test Modification—The SCAQMD Method 5.1 uses a tedious, math-intensive procedure for calibrating the gas-metering system (SCAQMD 1989). Following CE-CERT's recommendation, the draft STM will prescribe the K-Factor determination to calibrate the gas-metering system.

5. Impinger Train Setup Modification—The SCAQMD Method requires the filter be placed after the fourth impinger in the wet impingement train (Figure 15). This is a sufficient means to determining the total particulate matter emission, but there is poor differentiation between the solid and condensable particulate matter since both can be removed (to a degree) in the impinger train water. By placing the filter prior to the impingement train, solids at stack temperature are removed by the filter prior to the condensation of gases in the impingement train.



Note: The SCAQMD modified Method 5.1 required the filter be placed after the impinger bubblers (top). The Draft Emission STM will recommend the filter be placed before the impingers (bottom figure).

Figure 15. Filter Placement Variation

6. Data Reporting Modification—Particulate matter emissions concentration is not an absolute number. Since the sample volume changes with respect to the ventilation rate, comparisons between similar tests with varying ventilation rates become difficult. The use of emission

factors or emission rates is recommended for inclusion in the draft Emission STM. Emission factor is defined as the weight of particulate matter emissions for a given weight of food cooked. Emission rate is the weight of particulate matter emissions for a given test time.

2.11.2.2 Possible Challenges

Referencing other test methods presents an inherent problem. Both the EPA and the SCAQMD emission test methods refer to existing test methods for the determination of traverse points, stack velocity and stack flow rates, and stack gas density and moisture. These procedures are mandatory. One solution is to include these procedures into the draft STM, but that would more than triple the size of the test protocol. Another solution is to retain the references, but securing a copy of these protocols may be difficult. A third option may an optimum blend of the first two.

2.11.2.3 FSTC National Advisory Board Comments

- CE-CERT recommended heating the filter and probe assembly to stack temperature to avoid gas condensing in the probe. Presently, both the SCAQMD modified Method 5.1 and the proposed ASTM draft do not require heating the assembly.
- An advisor expressed concern with the pace of the test method development. A new national test method would jeopardize the validity of existing methods. Equipment that has been certified by UL and NFPA may be forced to undergo a new round of testing with the appearance of an ASTM standard. He suggested working with these organizations before approaching ASTM.
- Another advisor suggested that the ASTM Subcommittee is unqualified to ratify the test method. The group is comprised of manufacturers that do not have experience with emission testing. Though this is a valid argument, the draft will undergo an extensive peer review process prior to being submitted to ASTM. The strategy is to solicit involvement from the industry—i.e., research labs and commercial kitchen ventilation (CKV) equipment manufacturers.

2.11.3 Workshop on Commercial Kitchen Emissions

The FSTC hosted a Commercial Cooking Equipment Seminar: *Practical Limits in Emissions and Odor Control* at Pacific Gas and Electric Company's Energy Center in San Francisco last February 22, 1999. The agenda and an overview of commercial cooking emissions appear in Appendix V.

The workshop presented options for reducing cooking emissions based on research and real-world experiences. Topics included a discussion of a new restaurant rule (Rule 1138) as proposed by the South Coast Air Quality Management District for controlling emissions from chain-driven charbroilers used to cook meat (Appendix VI). The workshop addressed emission measurement protocols, characterization of emissions from the cooking processes; and the efficiency of existing emission control equipment. Forty people attended the workshop, with representation from a wide spectrum of the industry, including manufacturers, designers, code authorities and end-users. Post-seminar evaluations showed good response to the topics at hand with several attendees requesting further presentations in this area. The group encouraged taking take the emission data to the International Mechanical Code to impose uniformity in the industry, particularly with respect to when is a hood not required over commercial cooking equipment. In response to this issue, the FSTC team proposed criteria for not requiring a hood over cooking equipment (see second FSTC National Advisory Board presentation, Appendix IV).

2.12 Outcomes

The FSTC completed the build-out of a test cell and associated instrumentation for the measurement of emissions produced by commercial cooking equipment and processes. Furthermore, the FSTC was able to expand its testing capabilities and established itself as one of the few research centers in North America capable of characterizing emissions produced by commercial cooking processes. A draft standard test method for measuring PM and condensable vapor emissions from commercial cooking processes was developed as a basis for a national consensus standard test method (e.g., ASTM).

A successful workshop on cooking emissions was held February 22, 1999 at Pacific Gas and Electric Company's Pacific Energy Center in San Francisco. The workshop addressed new emission legislation in California; emission measurement protocols, characterizing emissions from the cooking processes; the efficiency of existing emission control equipment and a presentation / industry panel on case study experiences. The workshop drew 40 individuals, with representation from a wide spectrum of the industry.

2.12.1 Conclusions and Recommendations

The threshold values (i.e., upper limit) for PM, including condensable grease vapor, generated by discrete cooking appliances or from recirculating hood / appliance systems should be defined based on an emission rate (i.e., lb. / hr of PM) or an emission factor (i.e., lb. PM / 1000 lb. food cooked) rather than a PM concentration (e.g., 5 mg/m^3) that is independent of air flow rate (as is currently specified by UL 197). Data from this project suggest that this threshold PM production should be less than 0.01 lb. / h per appliance. Applying this to recirculating hoods, the minimum PM emitted into the kitchen space should be less than 0.005 lb. / h per linear foot of hood (based on the assumption that a typical (unhooded) appliance is typically 1.5 ft. wide). However, significantly more research is needed in this area to ratify such criteria for when (1) an appliance does not need a hood and / or (2) when a recirculating hood / appliance system are acceptable from both a fire safety and an indoor air quality perspective.

3.0 Commercial Kitchen Ventilation System Performance Evaluation and Optimization

3.1 Background

Although the opportunities for energy conservation and load management in commercial kitchen ventilation (CKV) are large, the lack of publicly documented lab and field data has made achieving such savings difficult. Based on a survey of CKV equipment manufacturers (Telephone Survey 1993) and recently published data, total kitchen ventilation exhaust in the United States appears to be in the range of 2.5 to 3.0 billion cfm. Table 5 shows a summary by industry segment. Data published by Cahners Bureau of Foodservice Research showed that an estimated total of 737,000 food service facilities were in operation in 1992. (Restaurants and Institutions January 1993) The California Restaurant Association estimates that there are more than 70,000 food service operations in California, or about ten percent of the national total. The per unit exhaust volumes are estimates based on collective design experience and knowledge of installed systems by researchers. (Claar 1995)

Table 5. Summary of Ventilation Volumes by Facility Type in the United States.

Industry Segment	Number of Units	Estimated Exhaust Per Unit (cfm/unit)	Total Exhaust (Million cfm)
Fast Food	180,125	3,000	540
Full Service	196,250	6,000	1,177
Educational	92,460	3,500	319
Health Care	63,730	3,500	219
Grocery & Retail	106,425	600	67
Lodging, Rec.	64,875	4,300	281
Other	33,300	4,400	146
Grand Totals	737,165	3,700	2,749

Initial research in kitchen ventilation demonstrated a significant potential in energy savings by reducing net exhaust. For example, exhaust hood face velocities of 100 to 150 feet per minute (fpm) are dictated by code, but levels as low as 50 to 75 fpm have been shown to be satisfactory. (Giammer 1971) An experimental study (Talbert 1973) published by ASHRAE reported that for wall and island canopies, only 40 to 50 percent of the normal design flow was required to provide satisfactory capture of smoke generated at any location on or beside the cooking surfaces. These studies are consistent with research and development conducted by McDonald's Corporation. (Soling 1985)

In general, their laboratory-based hood design and sizing procedures have allowed McDonald’s to install backshelf hoods that operate at exhaust ventilation rates that are significantly below code (e.g., 150 cfm / ft vs. 300 cfm / ft). Recent research at the CKV Laboratory (now sponsored by Pacific Gas and Electric Company) has demonstrated consistent reductions (20 to 50 percent) across different styles of exhaust hoods by making relatively simple design changes. Total estimated savings should average between 20 percent and 30 percent, with some facilities as high as 60 percent. (Claar 1995) Results from computer modeling of fast food and full service facilities support this estimate as well. (EPRI 1996)

Total cost savings across the industry could range from $1.0 to $1.5 billion per year. Savings in California could be over $100 million annually, if good design practices are implemented over the next twenty years. A reduction in CKV rates would:

- Improve energy efficiency in restaurants.
- Lower restaurant demands (often at system peak hours).
- Reduce capital construction costs by decreasing the size of installed HVAC equipment.
- Have a positive impact on the environment by reducing utility loads at the source and reducing effluent discharged from CKV systems to the atmosphere.

In addition to the energy/load management benefits that can be achieved through a direct cfm reduction in exhaust capacity, significant benefits can be realized through integrated HVAC design strategies, engineered equipment, and enhanced system control and operation. Optimizing systems and operating strategies for food service facilities during retrofit and new construction will present additional opportunities that will not be at the expense of customer or employee comfort.

To achieve the potential savings in California, PG&E proposed that an advanced research and demonstration facility for kitchen ventilation be built at its Food Service Technology Center in San Ramon, California. The new laboratory equipment would be used to research issues posed by the California restaurant industry and serve as a hands-on demonstration center for kitchen designers, mechanical engineers and contractors, architects, and food service facility operators. To inform this audience regarding recent research results, Pacific Gas and Electric Company proposed to prepare a design guideline and to present a workshop as part of the project.

3.2 Project Objectives

The objectives were to:

- Upgrade an existing test cell to permit measurements to support heat gain calculations from appliances under different styles of hoods.
- Add a sophisticated air flow visualization system for research and demonstrations of exhaust hood performance.
- Install an Air Flow Measurement System for the Ventilation (Calorimeter) Test Cell
- Prepare an introductory design guide.
- Complete development of an outdoor air load (heating, cooling and fan energy) software package called the Outdoor Airload Calculator.
- Present a workshop for kitchen designers, mechanical engineers, contractors, architects, and food service facility operators.

3.3 Procedures and Outcomes

3.3.1 Instrument Calorimeter Test Cell for Heat Gain Calculations

Heat gain calculations require measurement of supply and exhaust air temperatures, barometric pressure, differential pressure, and electric and gas appliance energy consumption. Data collection was performed with new instrumentation, a new Pentium-class computer, and customized data acquisition software based on the existing system at the CKV Lab.

Heat gain to the space is determined indirectly by monitoring make-up air volumetric flow rate, the temperature of make-up air moving toward the operating appliance / hood combination, the temperature of the air moving through the exhaust duct, and the energy input into the appliance (Figure 16).

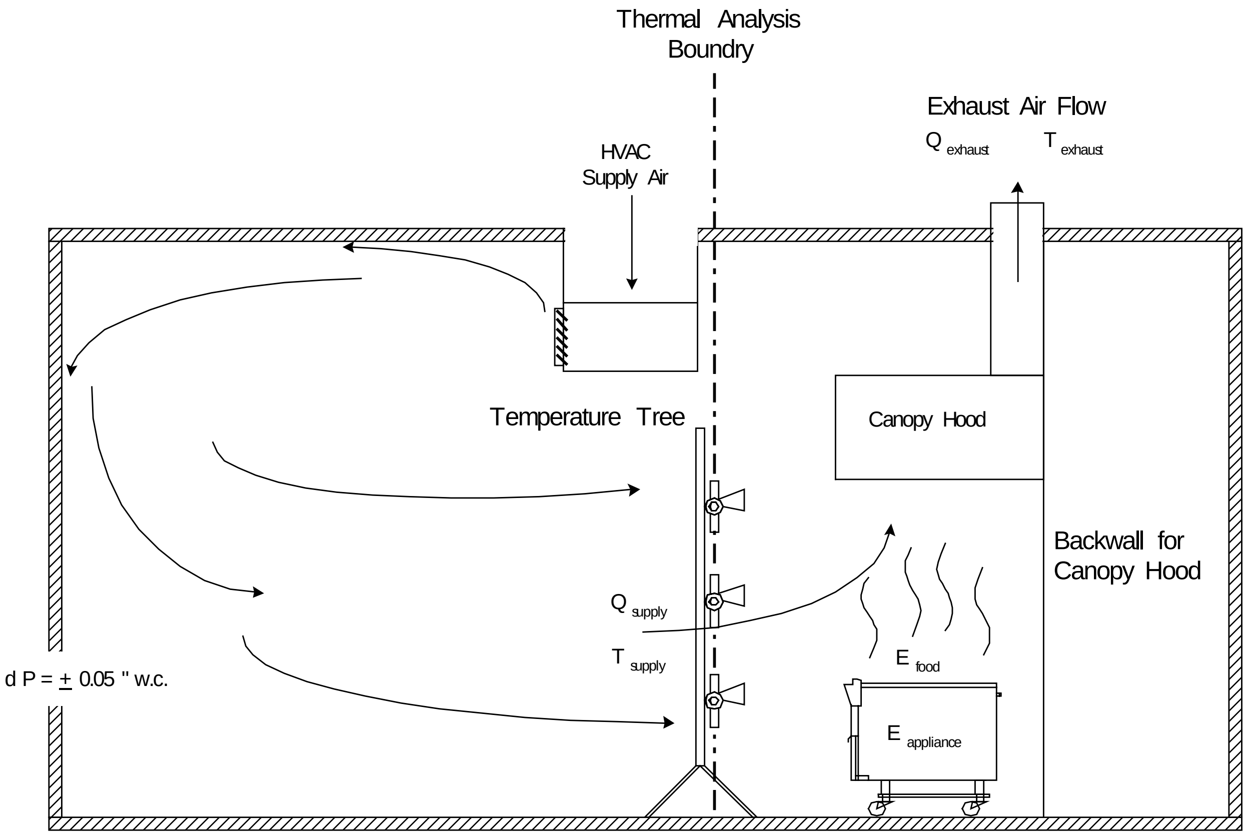


Figure 16. Cross-Section of Typical Heat Gain Test Cell Setup.

During a typical test, a given airflow rate and appliance energy input condition are maintained for two hours or less. Base on experience at the CKV Lab, the heat transfer across the test cell envelope during this period can be considered negligible. This condition permits heat gain to space calculations based on the following energy balance.

$\mathbf{\sum E_{in} = \sum E_{out}}$

or

$\mathbf{E_{appliance} + E_{make\ up\ air} = E_{exhaust} + E_{heat\ gain} + E_{food}}$

for the cooking case

$E_{heat\ gain} = E_{appliance} + E_{make\ up\ air} - E_{exhaust} - E_{food}$

and for the idle case

$E_{heat\ gain} = E_{appliance} + E_{make\ up\ air} - E_{exhaust}$

However, if the energy of the make up air is calculated at a plane three feet in front of the hood by a set of aspirated "temperature trees", the equation for the idle case reduces to:

$E_{heat\ gain} = E_{appliance} + E_{tree} - E_{exhaust}$

or

$E_{heat\ gain} = E_{appliance} - m\ c_p\ [T_{exhaust} - T_{tree}]$

or

$E_{heat\ gain} = E_{appliance} - 1.08\ Q\ [T_{exhaust} - T_{tree}]$

where m = mass flow rate of total make-up air (lb_a / h),

c_p = specific heat of air stream supplied to hood (0.244 Btu / lb_a °F and

Q = volumetric flow rate supplied to hood (CFM).

Heat Gain Test Station:

The heat gain test station consists of a PC controlled rack mounted measurement and control system with the following components (Figure 17):

- UPS: This uninterruptable power supply protects all equipment inside the instrumentation rack from power surges or from power outages for up to 20 minutes.
- Subsystem Industrial PC: This industrial PC is made by ICS Advent and runs custom software in a Microsoft WindowsNT environment. The PC has a Pentium-II 500MHz CPU and 128 MB of memory. This PC communicates with data acquisition equipment through Fast Ethernet and GPIB bus. The custom software processes incoming information and reacts appropriately to certain incoming signals to maintain stable heat gain test conditions.
- Subsystem Opto22 Control System: The Opto22 system is used to process digital and analog measurements and to send control signals to the exhaust and supply fans.

Figure 17. Heat Gain Measurement Instrumentation Rack

Table 6 summarizes the function of each module in the Opto22 measurement system.

Table 6. Opto22 Modules.

Count	Equipment Name	Description
1	Opto B-3000 ENET	Ethernet Brain that facilitates communication between Opto22 Snap modules for signal input/output and a control PC using fast Ethernet
1	Opto SNAP-B16M	16 module rack that accommodates all Opto22 components.
1	Opto SNAP ODC5SNK	4-channel switch for output, used to allow the control PC to switch equipment and control lights on and off
2	Opto SNAP IDC5-FAST-A	4-channel digital input used as digital counters for natural gas consumption, electric consumption, and other pulse signal inputs.
2	Opto SNAP AIV	2-channel voltage input for +/- 10 VDC. These modules are used to read ventilation damper settings, the signal from a barometric pressure transducer, dewpoint meter, and signals from other voltage control circuits.
2	Opto SNAP AIMA	2-channel current input for +/- 20 mADC. These modules are used to read signals from pressure sensors for laboratory differential pressure (lab<->ambient), Pitot tube array pressure drop, and for other current loop control circuits.
1	Opto SNAP AOV-25	2-channel voltage output 0..10 VDC. This module is used to control the exhaust fan flow and a supply fan damper for automatic ventilation flow rate adjustment.
1	CNET PowerSwitch CNSH-800	Fast Ethernet switch to connect this and potentially more Opto22 modules to the PC, as well as to the local Ethernet for data exchange.

Temperature Measurement:

The heat gain calculations called for a great deal of precision in the temperature measurements. To increase the measured precision over the standard ±1°F provided by standard thermocouple wire, researchers specified resistive thermal devices (RTDs). The specified RTDs are accurate to within ±0.06 percent of the measure reading.

The thermal boundary in Figure 17 is established using aspirated temperature trees (Figure 18).

Figure 18. Bulk Airflow Temperature Measurement Tree and Temperature Tree Sensor Array

The sensor array consists of three shielded open pipes with a RTD located at the center (Figure 19. Air is drawn from above and below each pipe, then pulled past the temperature sensor using a small exhaust fan.

Figure 19. Temperature tree sensor array disassembled

Figure 20 illustrates the aspiration manifold for a temperature tree.

Figure 20. Temperature Tree Aspiration Manifold

Subsystem Temperature Scanner:

A high precision digital multimeter was specified for monitoring air temperatures. The system is capable of monitoring 40 RTDs per second with the accuracy required by the heat gain calculations. Table 7 summarizes the temperature measurement system's components.

Table 7. Temperature Measurement System.

Count	Equipment Name	Description
1	Keithley Instruments DMM 2002	Super high precision digital multimeter used to read signals from 4 wire RTD (Pt-100 Resistive Temperature Device) sensors.
1	Keithley Instruments Scanner 7001	This unit is a switching mainframe for fast and precise switching of 4 wire signals. The 40 RTD sensors are wired to switching cards in this scanner, which connects the signals one at a time to the DMM 2002 for temperature measurement.
2	Keithley Instruments Switch Module 7011	Each of these cards provides switching capability for up to 20 4-wire inputs.
1	Keithley Instruments KPCI-488	PCI type GPIB interface for the process control computer, which enables communication between the PC and the above Keithley Instruments devices.
40	SDI Pt-100 RTDs	High precision RTD sensors from Sensing Devices, Inc. These sensors are used for precision air temperature measurement for air approaching the heat gain test area inside the lab as well as exhaust temperature measurement. In both cases an array of sensors is used to provide spatial temperature resolution for maximum accuracy. All RTD sensors are wired using plenum rated CAT-V network cable and 5-pin DIN connectors.
3	RTD trees	These trees are used to mount the ambient air temperature sensors. They aspirate the RTDs using hoses connected to a small exhaust fan, while shielding them from heat radiation.

Pressure Transducers:

Pressure transducers were required for monitoring the airflow into the laboratory, maintaining a balance between exhaust and supply air, and accurately measuring the barometric pressure during each test. Table 8 describes these sensors

Table 8. Pressure Sensors.

Count	Equipment Name	Description
1	Setra Model 204	Barometric sensor used to calculate air density and ultimately mass flow based on a volumetric flow measurement and temperature data.
2	Setra Model C264	Differential pressure transducers used to measure the following: The pressure drop across a Pitot tube array and to measure the volumetric air flow into the laboratory. The differential pressure between ambient air pressure and pressure inside the laboratory. This data enables the computer to match the exhaust flow exactly to the supply flow, which is important for exact heat gain results and laboratory safety.

The control PC communicates with the Opto22 system at least once per second to perform the following tasks:

- Check and correct the supply airflow rate,
- Check the differential pressure between the lab and the ambient environment and correct the exhaust flow appropriately,
- Check if the laboratory door is closed to validate the differential pressure reading, and
- Activate a warning light when major flow rate adjustments are performed to ensure the laboratory door won't remain open for extended periods of time during the flow adjustment.

The control PC communicates with Opto22 system and Keithley Scanner at a selectable scanning rate (>4 sec per cycle) to perform the following tasks:

- Read the temperature of all connected RTDs,
- Read all signals from the Opto22 subsystem, such as pressure signals, damper settings, and fan RPM,
- Calculate the volumetric airflow from Pitot tube pressure data,
- Calculate the mass airflow from volumetric airflow, temperature information, and humidity data,
- Calculate the energy balance between incoming airflow and outgoing airflow,
- Calculate the energy consumption of the appliance from natural gas meter data and electrical meter data,
- Calculate the heat gain balance as the difference of appliance input and exhausted power (=energy / time), and
- Write all input and output data to an output file with a time / date stamp.

3.3.1.1 Schlieren Flow Visualization System

The system chosen was a focusing schlieren flow visualization system manufactured by ViewStar, Inc. The image recording and processing system included a super VHS recorder and video board. The schlieren visualization system was initially shipped to the CKV Lab for commissioning.

ViewStar, Inc., the manufacturer of focusing schlieren flow visualization system, sent the system to the CKV Lab in the second week of January 1999. It was setup and successfully tested using a hood backwall made of clear plastic. Since that time it has been used for capture and containment testing and has been demonstrated to visitors attending the ASHRAE meeting in Chicago in January and the students from a University of Wisconsin short course on kitchen hoods and supply systems. Based on preliminary testing and observations, the research team decided to attempt to improve the video quality of the schlieren system by experimenting with different recording techniques and devices. The results using a color digital video camera with front lighting were far superior to previous recorded images.

Flow visualization is done with a custom-developed schlieren flow visualization system from ViewStar, Inc. This system allows non-intrusive investigation of hot air flow in real-time based on the refractive index dependency of air on temperature. Air in and surrounding the thermal plume from a cooking appliance changes its mass density and thereby its dielectric constant with temperature. This change in dielectric constant results in a change in refractive index, causing schlieren effect. The system at the CKV lab is capable of detecting a temperature difference of 5 °F per inch (0.11 °C per mm).

As a simple example of what is detected by the flow visualization system, schlieren effect can be observed on hot days as the flickering of air over hot pavement by the human eye. For comparison, the system at the Lab is sensitive enough to detect the warm air coming off a person’s body.

The schlieren focusing system at the CKV lab consists of a source grid at one end of the lab made of special reflective material to create a uniform pattern of light sources, shaped as white dots on a black background (Figure 21). This source grid is illuminated through an incandescent light source.

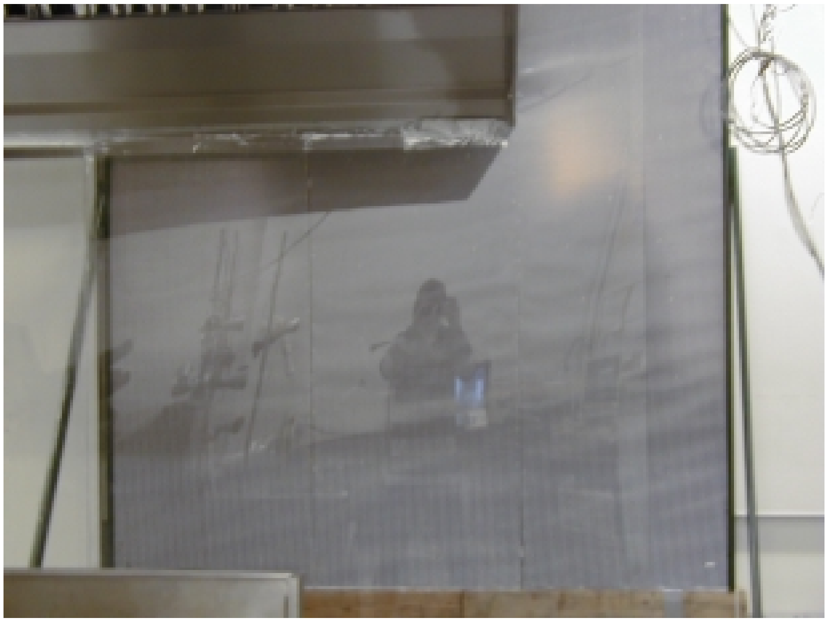


Figure 21. Source Grid for Schlieren Flow Visualization System

On the opposite side of the lab, an optical system projects the source grid, and objects between the source grid and optics, onto an image screen. Figure 22 and Figure 23 depict the schlieren optical box and viewing monitor. A photographically created negative image of the source grid, called a cut-off grid, is located immediately in front of that image screen.

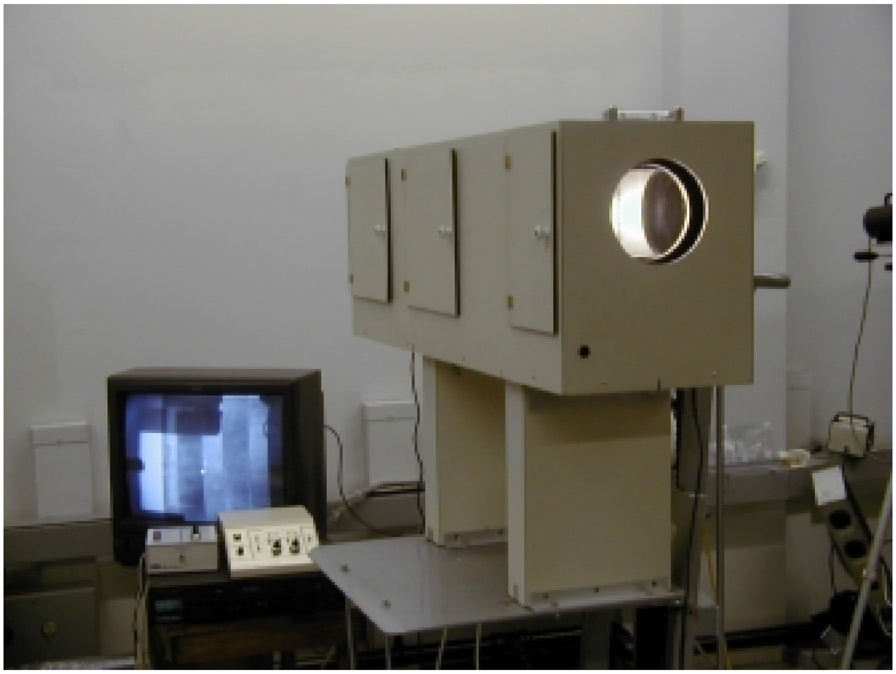


Figure 22. Schlieren Optical Box and Viewing Monitor

Figure 23. Side View of Schlieren Optical Box

Figure 24 illustrates the mounting frame for the cut-off grid.

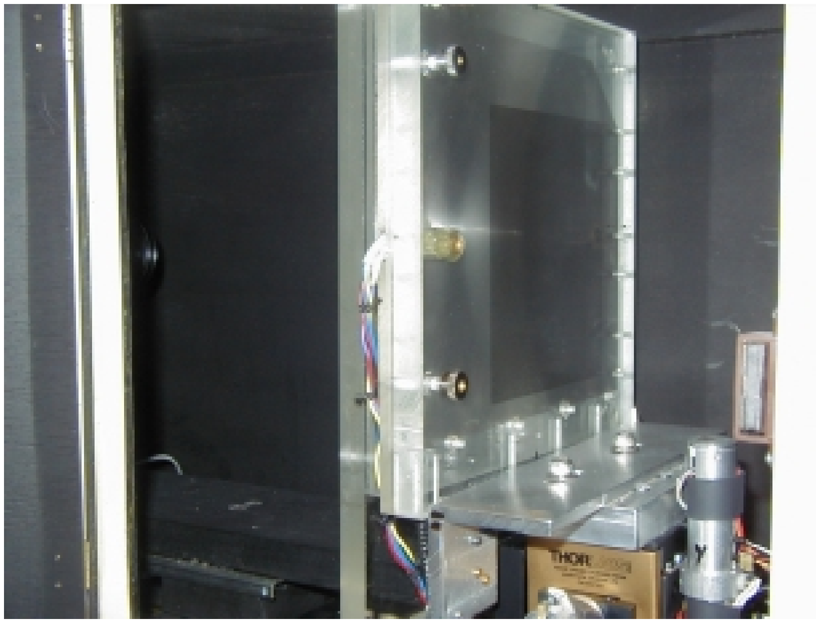


Figure 24. Mounting Frame for Cut-Off Grid.

As long as the refractive index of the air between source grid and cut off grid equals one constant value the cut off grid eliminates all the light coming from the source grid and the image on the screen is dark. As soon as the refractive index of the air between source grid and cut off grid changes, the image on the screen lightens up because the light rays from the source grid do not exactly match the black areas on the cut off grid.

The system as supplied by the manufacturer included an S-VHS video camera (Figure 25), which scans that image on the internal image screen of the schlieren system and transmits the signal to a TV monitor and an S-VHS VCR. To improve the quality of the recorded images, a Sony digital, color video camera was substituted for the S-VHS video camera.

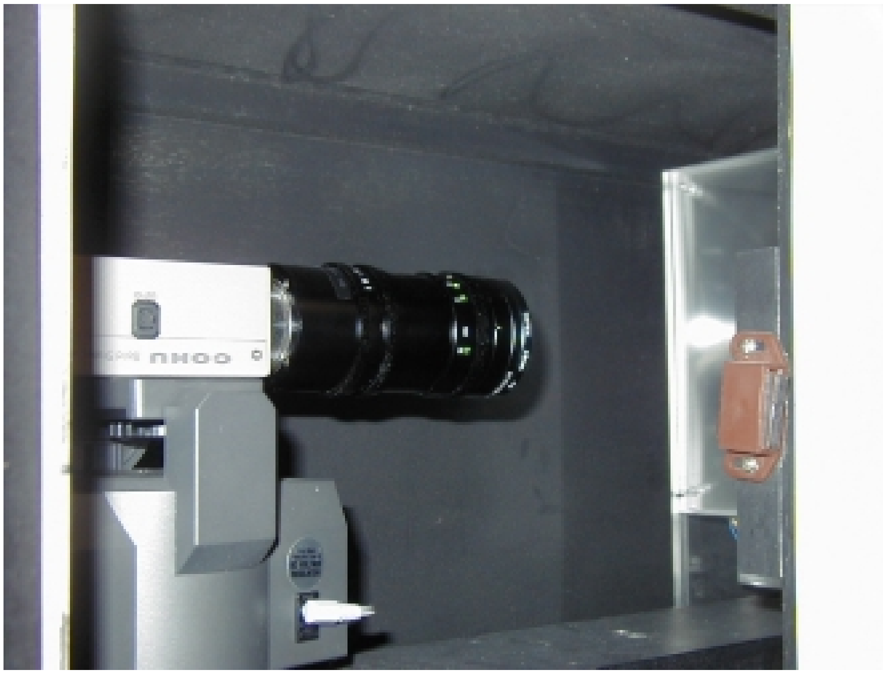


Figure 25. S-VHS Camera in Schlieren Optical Box

Additional flow visualization can be done with a Rosco Fog Machine, Model PF-1000, which has a maximum smoke generation rate of 250 CFM.

Figure 26 shows schlieren images of a clear, hot air plume (left two photos) and cooking plume (right side photo), with independent makeup air delivery.

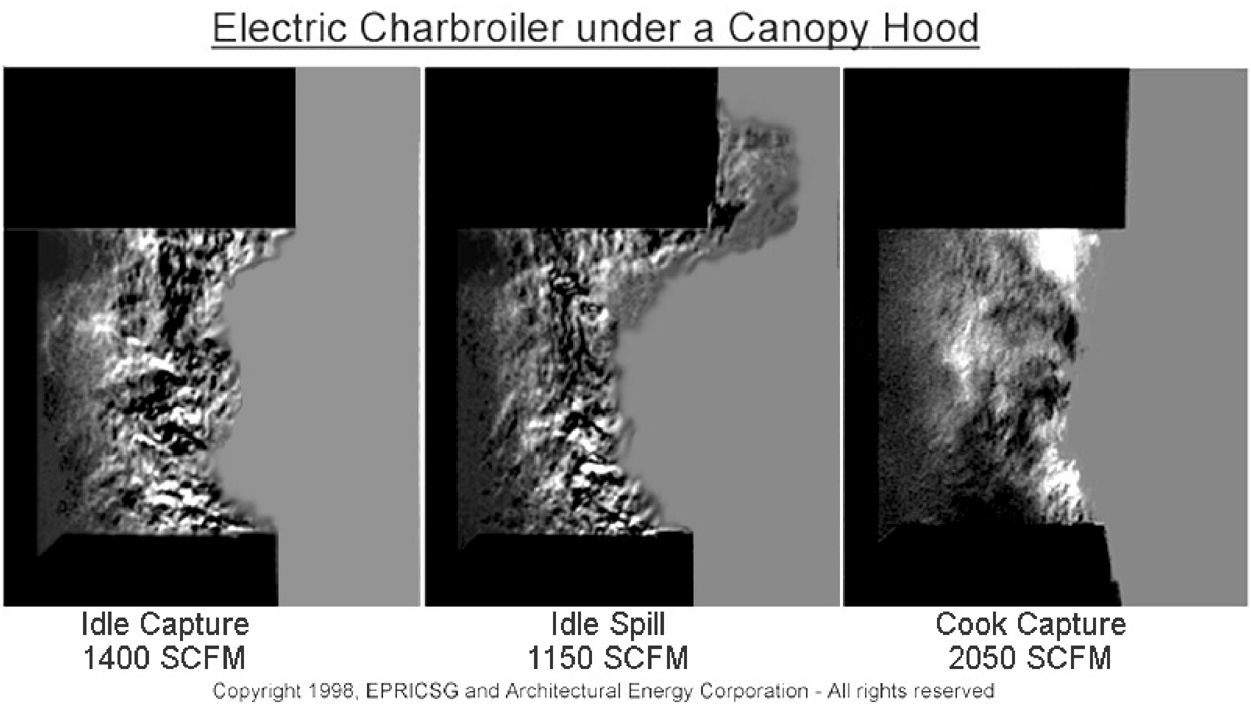


Figure 26. Schlieren Documentation of a Clear, Hot Air Plume (Left Two Photos) and Cooking Plume (Right Side Photo), with Ideal (Independent) Makeup Air Delivery.

3.3.1.2 Airflow Measurement System for the Heat Gain Test Cell

Instrumentation associated with the airflow measurement system included differential pressure sensors, dry-bulb temperature sensor, and humidity sensor. Data collection, storage, and processing will be accomplished with an existing computer system. An existing variable speed air handler, controlled by an existing computer system, was used to adjust airflow rate.

After inspecting the test cell, the design team decided to use a manufactured airflow monitoring station, in lieu of a laminar flow element or built-up nozzle chamber, because provided an economical solution with the desired level of accuracy.

The airflow measuring station selected is a 16-in. diameter FAN-Evaluator model manufactured by Air Monitor Corporation, Santa Rosa, California. The airflow measuring station contains multiple total and static pressure sensors positioned at the center of equal and symmetrical areas of the station cross-section and interconnected by their respective averaging manifolds (Figure 27).

Figure 27. Airflow Measuring Station

The heart of the station is an open parallel cell air straightener–equalizer honeycomb that permits accurate sensing of total and static pressures in very small longitudinal distance in the supply duct. According to the manufacturer's specifications, the maximum allowable pressure loss through the station does not exceed .015" w.c. at 1000 fpm, or .085" w.c. at 2000 fpm. The station is specified to be capable of measuring the airflow rate within an accuracy of 2 percent as determined by U.S.G.S.A. certification tests. A set of external signal connection fittings from the monitoring station is connected to the heat gain instrumentation system described in Section 2.

3.3.2 Prepare A Set of Guidelines for CKV Design Optimization for the California Restaurant Industry

The guidelines focused on recommended practices for design conditions commonly found in food service facilities in the State of California.

A draft of the guideline document was distributed at the workshop for comment by industry participants. The final draft incorporates comments from the workshop as well as new information that became available after the workshop. A copy of the final document is attached (Appendix VIII).

3.3.3 Complete CKV Cost Modeling Tool

FSTC developed a web-based tool to quickly and accurately determine heating and cooling loads for outdoor (makeup) air was developed. Since this tool does not model a complete building in detail, the minimal required input parameters are only geographic location, outdoor air flow, operating hours, and the heating and cooling set points. With these basic inputs, the Outdoor Airload Calculator (OAC) is able to calculate monthly and annual heating and cooling loads as well as design loads (the maximum heating and cooling load that occurred during the year). Through a “Details” menu it is possible to further customize the calculation setup for different fan types, dehumidification, and also equipment lockout during parts of the year.

The OAC is a component of a commercial cooking appliance energy-use model being developed by Pacific Gas and Electric Company in support of its food service customers. It is available as freeware over the World Wide Web or on local computers. The only system requirement is a web browser that supports Java 1.1. This architecture makes the OAC available to users on many computing platforms, from large UNIX based systems over Macintosh compatible computers to Windows based PCs.

The OAC uses weather data in four hour bins for the calculation of heating and cooling loads. Weather data is currently available for 239 US locations, 47 locations in Canada, and 16 general climate zones in California. The individual weather data files contain dry bulb temperature and relative humidity with a time and date stamp.

The US weather files were created from Typical Meterorological Year 2 (TMY2) data files, provided by the National Renewable Energy Laboratory (NREL). TMY2 data files represent a typical meteorological year in hourly format. For increased space efficiency, while maintaining reasonable accuracy, the hourly weather data was reduced to 4-hour bin data through averaging. That way the annual weather data, consisting of 8760 hourly readings, gets reduced to 2190 data points. The 4-hour bin data makes the output heating and cooling load sensitive to the time-of-day that a ventilation system is operating.

The Canadian weather files were based on Weather Year for Energy Calculations (WYEC) data. This is also an hourly data format. The WYEC files were processed similarly to TMY2 data files to convert them to the previously described 4-hour bin format.

The OAC offers two reporting formats: (1) a text window contains printed text output with all simulation details and results, and (2) a spreadsheet-like table for comparative simulations. The text window report is especially useful to end users because of its readability. Restaurant and building operators can perform a simple and quick analysis of their facility while browsing the Internet. For comparative simulations the OAC offers a table output screen. This spreadsheet like table is useful to quickly determine the savings potential of various equipment settings and operations schedules. Both report forms can be transferred into other computer applications for further analysis.

Figure 28 shows a sample output screen from the Outdoor Airload Calculator.

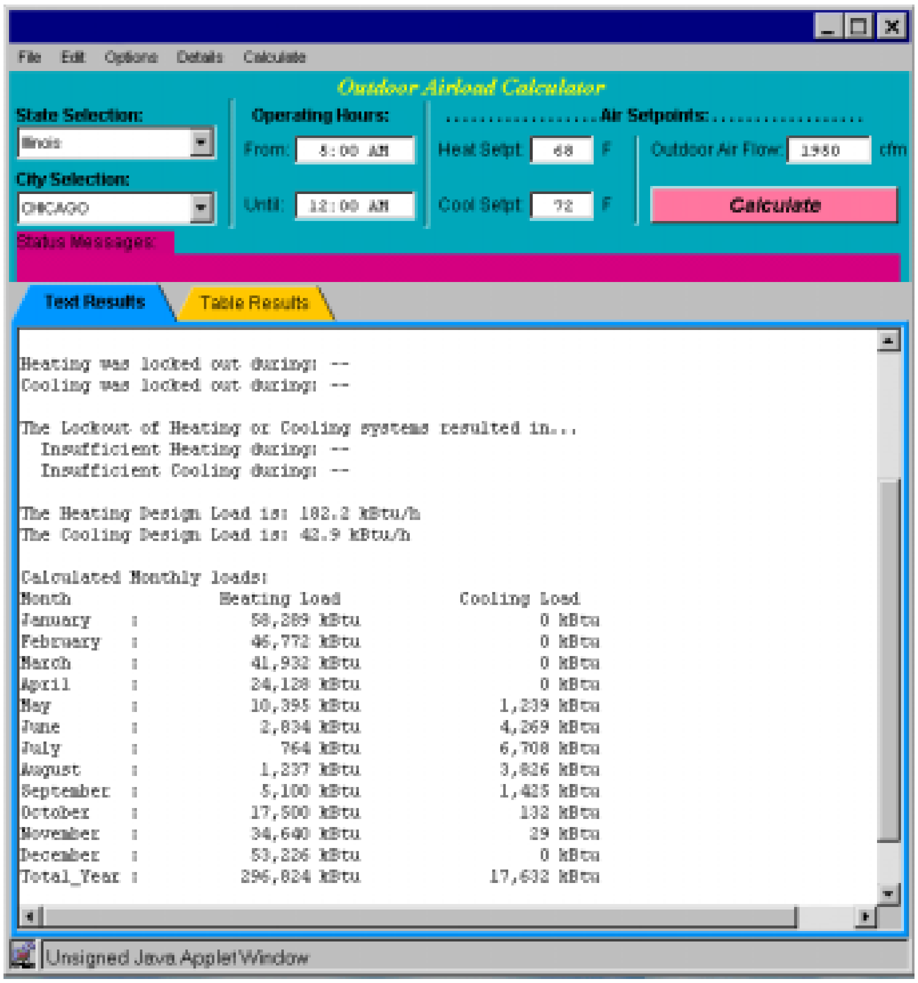


Figure 28. Screen image of Outdoor Airload Calculator

The OAC is available as freeware over the World Wide Web at http://www.archenergy.com/AECHome/ckv/oac/default.htm.

The only system requirement is a web browser that supports Java 1.1. This architecture makes the OAC available to users on many computing platforms, from large UNIX based systems over Macintosh compatible computers to Windows based PCs.

3.3.4 Present a Workshop on Commercial Kitchen Ventilation

The FSTC research team at the Pacific Energy Center in San Francisco, California presented a one-day workshop for food service consultants, design engineers, food service owner/operators, and building inspectors. The workshop was held in September and October 1998.

The seminar discussed the various aspects and latest developments of commercial kitchen ventilation research. Topics included the energy intensity of HVAC systems, dispelling CKV myths, optimizing design strategies and increasing energy efficiency, introducing new software for calculating ventilation energy costs, and an update on ASHRAE activities and research.

There were 70 attendees from across the industry, promoting a very interactive session. Participant feedback reinforced the need for continued commercial kitchen ventilation research and transfer of the information to the industry. Appendix VII includes the workshop agenda.

3.4 Conclusions

The instrumentation and software packages were selected, installed, and commissioned within the original budget. The new laboratory equipment will allow the Food Service Technology Center to research issues posed by the California restaurant industry and to serve as a hands-on demonstration center for kitchen designers, mechanical engineers and contractors, architects, and food service facility operators.

The focusing schlieren system is a major breakthrough for visualizing thermal and effluent plumes from hot and cold processes, particularly in food service, as it allows non-intrusive investigation of hot air flow in real-time. One of the real advantages of this flow visualization technique is the ability to document the dynamic air flow patterns on videotape. This ability could be used to explore the affect of different design strategies on the capture and containment performance of commercial kitchen ventilation systems.

The Outdoor Airload Calculator will not only be beneficial to kitchen designers and mechanical engineers and contractors, but to food service facility operators as well. The tool quickly and accurately estimates heating and cooling loads for a building, based on location. Designers can use the tool to size equipment and food service operators can use it to project energy savings for different heating and cooling setpoints.

The workshop on commercial kitchen ventilation was well received—drawing 70 attendees from across the industry and promoting a very interactive session. Participant feedback reinforced the need for continued commercial kitchen ventilation research and transfer of the information to the industry. The guidelines for CKV design optimization were distributed at the workshop and include the input of the various industry participants. These outreach activities were very successful and completed within budget as well.

Further research focusing on how the introduction of replacement (makeup) air affects the energy performance of commercial food service ventilation equipment was recommended and is being funded through a subsequent PIER project. This future research will focus on improving the energy efficiency of commercial kitchen ventilation systems by performing flow-visualization research and publishing design guidelines for the food service community.

4.0 Benefits to California

The results from this California Energy Commission transition PIER Project (and subsequent research conducted by the Food Service Technology Center as a result of testing capabilities established by the project) will benefit the public by reducing the particulates released to the atmosphere and kitchen environment by commercial cooking equipment. The project will benefit the state by developing a published method to measure commercial cooking equipment particulates. The project will also benefit utility ratepayers by reducing the amount of energy consumed by ventilation hoods and systems.

Until recently, the Air Quality Management Districts (AQMD) have not required particulate emissions controls on commercial kitchen ventilation equipment, allowing uncontrolled and unspecified amounts of grease and other particulate matter to be released into the atmosphere by restaurants. The adoption of Rule 1138 by SCAQMD regulating the release of PM and reactive organic gases from restaurants sets the stage for a new era in cooking equipment emission control. The premise is that air quality (outdoor and indoor) will be improved with effective methods to measure and control particulates.

It is anticipated that the funds expended on this project will serve the citizens of California over at least the next 10 years by providing hands-on information and knowledge regarding CKV systems. The outcome should be a net reduction in energy used for commercial kitchen ventilation.

5.0 Glossary

ARI	Air-conditioning and Refrigeration Institute.
AQMD	Air Quality Management District
AQMD	Air Quality Management District
ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers, Inc.
BDL	Below detectable limits
CE-CERT	College of Engineering—Center for Environmental Research and Technology
CFM	Cubic feet per minute
CKV	Commercial kitchen ventilation.
Concentration	Amount of material within a given volume
Emission Factor	Pounds of emissions per 1000 pounds of food cooked
Emission Rate	Pounds of emissions per hour
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute.
FSTC	Food Service Technology Center
FSTC	Pacific Gas and Electric's Food Service Technology Center in San Ramon, California.
HVAC	Heating, ventilation, and air-conditioning systems
IFMA	International Facility Management Association
kBtu	Kilo British thermal unit
NFPA	National Fire Protection Agency
OAC	Outdoor Airload Calculator. Software for estimating the monthly and annual heating and cooling loads for outdoor air used as makeup air.
PIER	Public Interest Energy Research
PM	Particulate matter
PSIG	Pounds per square inch gauge
RTD	Resistance thermal device – usually a platinum wire
SCAQMD	South Coast Air Quality Management District

SCFM	Cubic feet per minute at standard conditions
STM	Standard Test Method
TMY2	Typical Meteorological Year 2 is a database format for hourly weather data.
UL	Underwriters Laboratories
VOC	Volatile organic compound

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6.2 Commercial Kitchen Ventilation System Performance Evaluation

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International Building Mechanical Code, International Code Council, Inc. The Council is made up of the Building Officials and Code Administrators International, Inc., the International Conference of Building Officials, Inc., and the Southern Building Code Congress International, Inc.

APPENDIX I

EXAMPLE SOURCE TEST DATA AND CALCULATIONS

APPENDIX II

DRAFT STANDARD TEST METHOD

APPENDIX III

FSTC NATIONAL ADVISORY BOARD MEETING #27 PRESENTATION

APPENDIX IV

FSTC NATIONAL ADVISORY BOARD MEETING #28 PRESENTATION

APPENDIX V

EMISSIONS WORKSHOP AGENDA AND OVERVIEW PRESENTATION

APPENDIX VI

SCAQMD RULE 1138, CONTROL OF EMISSIONS FROM RESTAURANT OPERATIONS

APPENDIX VII

COMMERCIAL KITCHEN VENTILATION SEMINAR FLYER AND AGENDA

APPENDIX VIII

COMMERCIAL KITCHEN VENTILATION GUIDELINE FOR CALIFORNIA

APPENDIX I

Example Source Test Data and Calculations

Test No. :	120498	Test Date :	04-Dec-98
Sampling Location :	Food Service Technology Center Labs	ID:	Half-Size Bakery Oven #1
Sampling Train :	EPA Methods 5.1/202	Input by :	Clem Da Silva

SOURCE TEST CALCULATIONS (VELOCITY)

Pre-test Velocity Leak Check:	OK	Post-Test Velocity Leak Check:	OK
Stack Width:	8.0 in		
Nozzle Diameter:	0.1875 in	Gas Meter Correction Factor:	1.2188
Nozzle Cross Area:	0.000192 ft^2	Pitot Factor:	0.840
Barometric Pressure:	30.16 in-Hg	% of Moisture:	1.37
Static Pressure in Stack:	0.02 in-water	Sampling Time:	90 min
Stack pressure:	30.16 in-Hg		
Velocity Head:	0.02 in-water		

Time (min)	Traverse Point	Meter Temp * In (°F)	Meter Temp * Out (°F)	Stack Temp (°F)	Gas Meter Reading	Sampling Rate (cfm)	Calc. Vel (fps)
0	5	56	59	95	640.520	na	8.1
10	5	57	45	91	641.700	0.197	8.1
20	5	59	44	94	642.600	0.150	8.1
30	5	58	44	96	643.600	0.167	8.1
40	5	58	43	95	na	na	8.1
50	5	56	43	94	646.100	na	8.1
60	5	57	43	93	647.150	0.175	8.1
70	5	56	43	98	648.250	0.183	8.2
80	5	56	43	98	649.400	0.192	8.2
90	5	56	45	96	650.640	0.207	8.1
Net Volume					10.120		
	Average	57.0	43.7	95.0			8.1

* These temperatures are estimates based on other tests with similar stack temperature profiles.

Test No. :	120498	Test Date :	04-Dec-98
Sampling Location :	Food Service Technology Center Labs	ID:	Half-Size Bakery Oven #1
Sampling Train :	EPA Methods 5.1/202	Input by :	Clem Da Silva

SOURCE TEST CALCULATIONS (EMISSIONS)

SUMMARY

Stack Width: 8.0 in — Nozzle Diameter: 0.1875 in

A. Average Traverse Velocity.. 8.134 fps

B. Gas Meter Temperature (Use 60 °F for Temp Comp. Meters.. 43.7 °F

C. Gas Meter Correction Factor.. 1.2188

D. Average Stack Temp. :	95.0 °F	J. Sampling Time :	90 min
E. Stack Cross Sect. Area :	0.44 ft^2	K. Nozzle Cross Sect. Area :	0.000192 ft^2
F. Barometric Pressure :	30.16 in HgA	L. Net Sample Collection :	9.7 mg
G. Total Stack Pressure :	30.16 in HgA	M. Net Solid Collection :	2.5 mg
H. Pitot Correction Factor :	0.840	N Water Vapor Condensed :	3.9 ml
I. Velocity Head:	0.02 in-water	O. Gas Volume Metered :	10.12 dcf

P. Corrected Gas Volume [((O x C) x (F + I/13.6))/ (460 + B)].. 13.03 dscf

PERCENT MOISTURE DENSITY

Q, Percent Water Vapor in Gas Sample [(4.64 x N) / ((0.0464 x N) + P)].. 1.37 %

R. Average Molecular Weight (Wet):

Component	Vol. Fract.	x	Moisture fract.	x	Molecular Wt.	=	Wt/ Mole
Water	0.0137		1.00		18		0.247
Carbon Dioxide	0 (dry basis)		0.99		44		0.000
Carbon Monoxide	0 (dry basis)		0.99		28		0.000
Oxygen	0.209 (dry basis)		0.99		32		6.596
Nitrogen & Inerts	0.791 (dry basis)		0.99		28		21.845
						SUM =	28.688

LAB ANALYSIS

S. Moisture Gain:	3.9 g
T. Organic Extract:	7.2 mg
U. Soluble:	0.9 mg
V. Insoluble:	1.6 mg
W. Filter	0 mg

X. Non-Condensable matter concentration [(V + W) / (P x 0.0283)] 4.3 mg/m^3

Y. Condensable matter concentration [(T + U) / (P x 0.0283)] 22.0 mg/m^3

Z. Total matter concentration [X + Y] 26.3 mg/m^3

AA. Isokinetic Sampling Rate [(0.0945 x (D + 460))/(A x G x J x K x (1 - Q/100))].. 164 %

APPENDIX II

Draft Standard Test Method

Standard Test Methods for Determination of Particulate Matter and Condensable Gas Emissions from Commercial Cooking Effluent[1]

Introduction

Measurement and comparison of particulate matter (PM) emissions from commercial kitchens are of general importance to researchers, code authorities, manufacturers and operators of food service facilities. Since there are numerous methods, comparisons of PM emission and size distribution from a cooking process are subject to inconsistencies. Data generated by one measurement protocol may be consistent in many respects, yet be troublesome to correlate due to variance in sampling procedure, lab analysis and data processing. Standardized protocol will reduce inconsistencies resulting from differing measurement practices, particularly with respect to grease produced by cooking processes.

1. Scope

1.1 This test method describes sampling procedures for both in-stack (in-duct) and in-plume determination of particulate emissions and particle size distribution from commercial kitchen cooking effluent. The food service industry can use the results from this protocol to evaluate compliance for new regulatory standards and the performance of emission control equipment and strategies.

1.2 This test method is patterned after SCAQMD Method 5.1 and EPA Method 202 and incorporates their procedures for measuring solid and condensable particulate matter emissions. This procedure is specifically written for cooking effluent and must be modified for sampling hygroscopic, acidic or ammonia latent emission source commonly found in industrial processes. This test method will test for the following (where applicable):

1.2.1 Effluent particulate matter (PM) concentration and condensable gases at a standard temperature of 15°C (60°F).

1.2.2 Effluent particle size distribution.

1.3 The standard units for sampling procedures are inch-pound units while the chemical analysis is in SI units. Values given in parentheses are for information only.

1.4 *Since proper usage of apparatus is essential in obtaining valid results, all personnel involved in both collection and analysis of samples must be trained and experienced in the test procedures.*

1.5 *This test method may involve hazardous materials, operations, and equipment. This standard does not address all of the safety problems associated with its use. It is the responsibility of the users of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to its use.*

2. Referenced Documents

2.1 South Coast Air Quality Management District (SCAQMD) Documents[2]:

"*Method 5.1--Determination of Particulate Matter Emissions From Stationary Sources Using a Wet Impingement Train*," Offices of Operations, Technical Services Division, 1989.

"*Method 1.1—Sample and Velocity Traverses for Stationary Sources*" Offices of Operations, Technical Services Division, 1989.

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[1] This test method is a working document of Pacific Gas and Electric Company's Food Service Technology Center. With the consensus of industry representatives and other test facilities, it will be submitted to ASTM Committee F-26 on Food Service Equipment.

[2] Available from South Coast Air Quality Management District. Technical Service Division. 21865 E. Copley Drive, Diamond Bar, California.

"*Method 1.2—Sample and Velocity Traverse for Stationary Sources with Small Stacks or Ducts*," Offices of Operations, Technical Services Division, 1989.
"*Method 2.1— Determination of Stack Gas Velocity and Volumetric Flow Rate (S-Type Pitot Tube)*," Offices of Operations, Technical Services Division, 1989.
"*Method 2.2—Direct Measurement of Gas Volume Through Pipes and Small Ducts*," Offices of Operations, Technical Services Division, 1989.
"*Method 2.3— Determination of Gas Velocity and Volumetric Flow Rate From Small Stacks and Ducts*," Offices of Operations, Technical Services Division, 1989.
"*Method 3.1—Gas Analysis for Dry Molecular Weight and Excess Air*," Offices of Operations, Technical Services Division, 1989.
"*Method 4.1— Determination of Moisture Content in Stack Gases*," Offices of Operations, Technical Services Division, 1989.

2.3 ASTM Standard:
Method D2986 - 71 (for filter)[3].
ASTM specification D1193-99: Standard Specification for Reagent Water. (for DI water).

2.4 Environmental Protection Agency (EPA) Document:
"*Method 202- Determination of Condensable Particulate Emissions from Stationary Sources*," Emission Measurement Technical Information Center, Emission Measurement Branch, Technical Support Division, OAQPS, EPA, 1991[4].

3. Terminology

3.1 *Definitions:*

3.1.1 *calibration, n*—the process of submitting samples of known value to an instrument, in order to establish the relationship of value to instrumental output.

3.1.2 *cascade impactor, n*—an instrument that samples particles by impacting on solid surfaces via jets of air. After passing the first surface, the air is accelerated toward the next surface by a higher speed jet, in order to capture smaller particles than could not be captured by the previous one.

3.1.3 *desiccant, n*—a substance having an affinity for water. Used as a drying agent.

3.1.4 *desiccator, n*—a short glass jar fitted with an airtight cover and containing some desiccating substance (as calcium chloride), above which is placed the material to be dried or to be protected from moisture.

3.1.5 *downstream, n*—in the direction of the flow current of the stream.

3.1.6 *effluent, n*—waste material (as smoke, liquid industrial refuse, or sewage) discharged into the environment especially when serving as a pollutant.

3.1.7 *flow rate, n*—speed or velocity of fluid movement usually measured in units of weight (or volume) per time.

3.1.8 *hygroscopic, adj*—characteristic of substance having the property of absorbing water vapor from air. Also pertains to a substance that have an affinity for water and whose physical characteristics are appreciably altered by the effects of water.

3.1.9 *insoluble, adj*—incapable of being dissolved in a particular liquid. Term used of solid that does not dissolve under specified attack. No known substance is completely insoluble, so the term refers to systems characterized by very low solubility.

3.1.10 *isokinetic sampling rate, n*—rate at which the velocity of the effluent is preserved as it enters the sampling apparatus.

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[3] Available from ASTM Standards. West Conshohocken, PA.
[4] Available from Environmental Protection Agency. Research Triangle Park, North Carolina 27711.

3.1.11 *particulate matter (PM), n*—solid or liquid particles of soot, dust, smoke, fumes, and aerosols.

3.1.12 *sampling time, n*—the period in which effluent is collected in the impinger train and data is monitored.

3.1.13 *soluble, adj*—capable of being dissolved in a fluid.

3.1.14 *stack, n*—any structure or part thereof that contains a flue or flues for the discharge of gases.

3.1.15 *static pressure, n*—pressure of a fluid whether in motion or at rest.

3.1.16 *traverse points, n*—a selection of points representative of an area.

3.1.17 *traverse sampling, n*—a representative measurement of volumetric flow rate from a stationary source in which the cross section of the stack is divided into a number of equal areas. Sampling taking place at the centroid of each of these equal areas.

3.1.18 *upstream, n*—in the direction opposite to the flow current of the stream.

3.1.19 *velocity head, n*—the constant difference of height of a liquid between a level surface in a reservoir and a uniformly flowing jet through an orifice.

4. Summary of Test Methods

4.1 The effluent generated from a controlled cooking process is captured by a hood and drawn through a duct length. A sample is isokinetically drawn, at predetermined traverse points, through a glass fiber filter and wet impingement train for capture of solid and condensable particulate matter. The filter catch is dried, desiccated and analyzed gravimetrically while the impingement catch is extracted, dried, desiccated and analyzed gravimetrically.

4.2 A personal cascading impactor is placed in the exhaust plume. The effluent enters the inlet cowl and accelerates through the six radial slots in the first impactor stage. Particulates larger than the cut-point of the first stage impact on the precut collection substrate. Then, the effluent flows through the narrower slots in the second impactor stage, smaller particles impact on the second collection substrate, and so on. The jet velocity is higher for each succeeding stage, and the smaller particles eventually acquire sufficient momentum to impact on one of the collection substrate.

5. Significance and Use

5.1 Solid and condensable emissions from cooking processes effect not only the comfort and safety of kitchen staff but the overall environment of the region. In urban congested areas, cooking emissions add to the existing pollutants and compromise the overall air quality. This test method provides a procedure for measuring particulate matter concentration from commercial cooking processes for evaluation under federal and local codes.

5.2 The cascading impactor distinguishes effluent particle size from the range of 0.4 to 21 microns. This information can be used by hood manufacturers to determine the efficiency of filter design.

6. Apparatus

6.1 Sampling Apparatus

6.1.1 *Probe nozzle*, shall be 316 stainless steel or glass, with a sharp, tapered leading edge. The taper angle shall be ≤ 30° and on the outside, to preserve a constant internal diameter. The stainless steel nozzle shall be constructed from seamless tubing. A range of nozzle sizes suitable for isokinetic sampling shall be available in increments of 0.16 cm (1/16 in.), e.g. from 0.32 to 1.27 cm (1/8 to 1/2 in.) or larger if higher volume sampling trains are used.

6.1.2 *Probe Liner*, shall be borosilicate or quartz for stack temperatures up to about 480°C (900°F); quartz liners for temperatures between 480 to 900°C (900 and 1,650°F). When assembling the probe and nozzle, verify that all components, including ferrules and other connectors, are heat-resistant, leak-free and non contaminating for the sample. The liner may be connected to the impingers rigidly with glass, or flexibly with inert vacuum tubing.

NOTE 1—metal liners made of seamless tubing (e.g. 316 stainless steel, Inconel 825 or other corrosion resistant metals) my be used when acid particulates are present in concentrations less than 1 mg/m3 at probe conditions or SO2 is less than 20 ppm.

6.1.3 *Pitot Tube*, Use an S-type pitot tube as described in SCAQMD Section 1.1 of Method 2.1. Attach the pitot tube to the probe, as shown in Figure 1, to allow constant monitoring of the stack gas velocity. If this is not practical see SCAQMD Chapter X, section on Flue Factor. The impact (high pressure) opening plane of the pitot tube must be even with or above the nozzle entry plane (see SCAQMD Method 2.1) during sampling. The S-type pitot tube assembly must have a known coefficient, as determined in Method 2.1

6.1.4 *Differential Pressure Gauge*, Use an inclined manometer or equivalent device, as described in SCAQMD Method 2.1, for stack velocity head readings, and a separate manometer for orifice differential pressure readings.

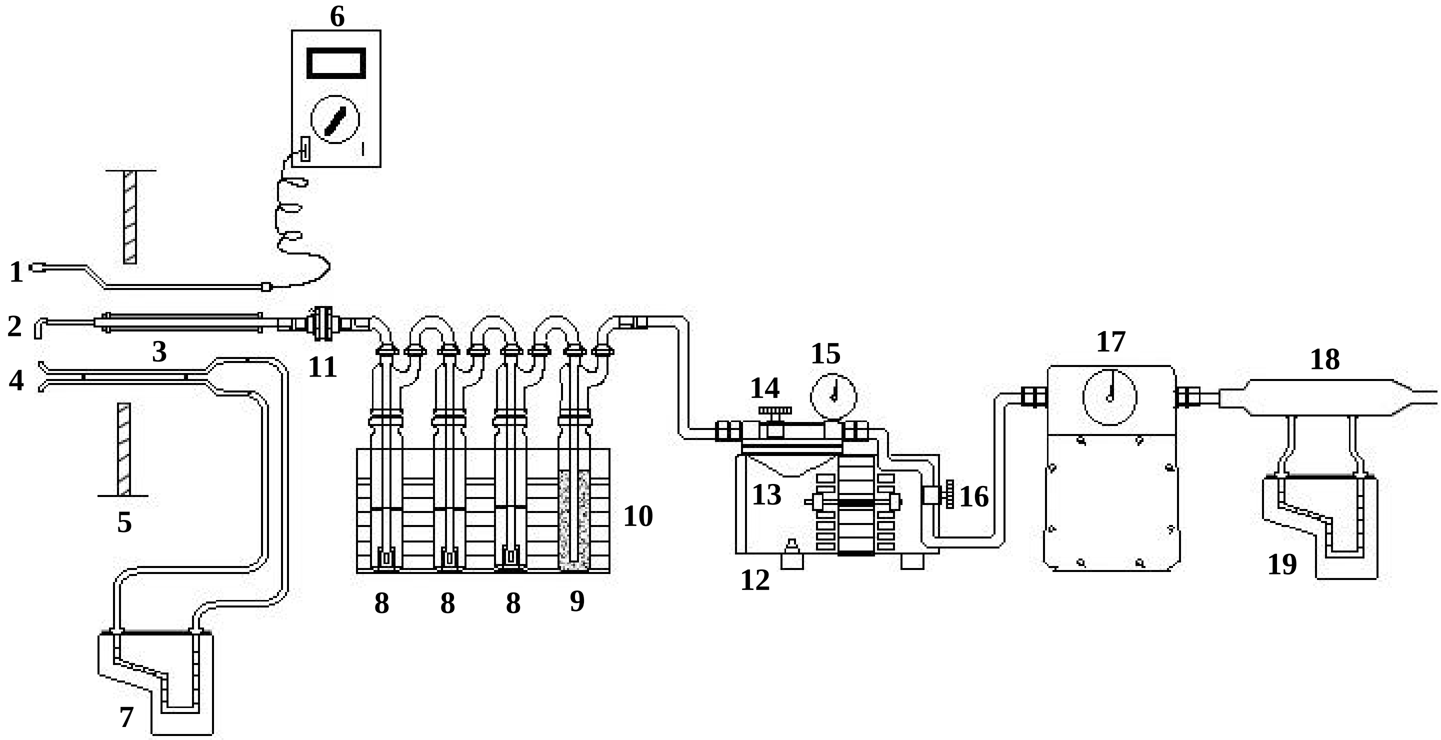
6.1.5 *Filter Holder*, shall be borosilicate glass filter holder, with a glass frit filter support and a silicone rubber gasket. The holder design provides a positive seal against leakage from the outside or around the filter. Attach the holder to the first impinger in the impinger train.

6.1.6 *Impinger Train*, consisting of four Greenburg-Smith design impingers connected in series with leak-free ground glass fittings, or any similar leak-free non-contaminating fittings. The second and third impingers must be of the Greenburg-Smith design with the standard tip. The first and fourth impingers must be of the Greenburg-Smith design, modified by replacing the tip with 1.3 cm (1/2 in.) ID glass tube extending to about 1.3 cm (1/2 in.) from the bottom of the flask. Acceptable modifications include the following: using non-reactive flexible connections between the impingers, using materials other than glass, or using flexible vacuum lines to connect the filter holder to the impinger train.

The first impinger remains empty, while the second and third impingers contain 100 ml of deionized water (run blanks prior to field use). The forth contains a known weight of 6 to 16 mesh indicating-type silica gel or equivalent. Place a thermometer capable of measuring temperature to within 1°C (2°F) at the outlet of the fourth impinger to monitor outlet gas temperature. In certain applications an extra dry impinger with a shortened straight stem may be placed before the wet impinger to act as a drop out for particulates that cause excessive foaming, or when there is excessive moisture. Instead of using silica gel, the moisture leaving the third impinger may be measured by monitoring the temperature and pressure at the exit of the impinger train and using Dalton's law of partial pressures.

Even if means other than silica gel are used to determine the amount of moisture leaving the impinger train, silica gel, or equivalent should be used between the impinger system and pump to prevent moisture condensation in the pump and metering devices.

NOTE 2—Do not use silicone grease or other binders to seal glass-to-glass connections since they may contaminate the sample. PG&E found that water is an excellent sealant for glass-to-glass contact.



1. Temperature Sensor
2. Nozzle
3. Glass Lined Stainless Steel Probe
4. S-Type Pitot Tube
5. Stack Wall
6. Temperature Sensor Meter
7. Pitot Tube Inclined Manometer
8. Impinger with 100 ml H_2O
9. Bubbler with Silica Gel
10. Ice Bath
11. Filter
12. Sealed Pump (Leak Free)
13. Filter for the Pump
14. Metering Valve
15. Vacuum Gauge
16. By-Pass Valve
17. Temperature Compensated Dry Gas Meter
18. Orifice
19. Orifice Inclined Manometer

Figure 1: Particulate Sampling Impingement Train Setup

6.1.7 *Metering System*, including a vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 3°C (5.4°F), dry gas meter capable of measuring volume to within 2 percent, and related equipment, as shown in Figure 1. An alternative to the thermometer and dry gas meter is an equivalent temperature compensated dry gas meter. When the metering system is used in conjunction with a Pitot tube, the system should allow for checks of isokinetic rates.

6.1.8 *Barometer*, for measuring atmospheric pressure. capable of measuring atmospheric pressure to within 2.5 mm (0.1 in.) Hg. Shall have a resolution of 2.5 mm (0.1 in.) Hg and an uncertainty of 2.5 mm (0.1 in.) Hg.

6.1.9 *Temperature Determination Equipment*, for measuring exhaust temperature, shall be type K thermocouple wire with a range of 10°C to 900°C (50°F to 1650°F) and an uncertainty of ±2°C (±1°F). The temperature sensor shall be attached to either the pitot tube or to the probe extension, in a fixed configuration. If the temperature sensor is attached in the field, the sensor shall be placed in an interference-free arrangement with respect to the S-type pitot tube opening. Alternatively, the temperature sensor need not be attached to either the probe extension or pitot tube during sampling, provided that a difference of not more than 1 percent in the average velocity measurement is introduced.

6.2 Sample Recovery Apparatus

6.2.1 *Balance*, for weighing samples, with a resolution of 0.5 g (0.001 lb), and an uncertainty of 0.5 g (0.001 lb).

6.2.2 *Nylon Bristle Brush with Stainless Wire Handles*, for brushing out the probe liner and nozzles. The probe brush must have extensions at least as long as the probe, and made of stainless steel, Nylon, or Teflon, or similarly inert material.

6.2.3 *Wash Bottle*, glass wash bottles are recommended; polyethylene wash bottles may be used.

6.2.4 *Glass Sample Storage Containers*, 500 ml or 1000 ml chemically-resistant, borosilicate glass bottles. Screw cap liners must be rubber-backed Teflon or constructed to be leak-free and resistant to chemical attack. Narrow mouth glass bottles are less prone to leakage. Alternatively, polyethylene bottles may be used.

6.2.5 *Petri Dishes*, for holding filter samples, use glass or polyethylene.

6.2.6 *Plastic Storage Container*, air-tight containers to store silica gel.

6.2.7 *Funnel and Rubber Policeman*, to aid in transfer of silica gel to container; not necessary if silica gel is weighed in the field.

6.2.8 *Funnel*, glass or polyethylene, to aid in sample recovery.

6.3 Particulate Matter Analysis Apparatus

6.3.1 *Glass Weighing Dishes*.

6.3.2 *Desiccator*, containing indicating-type calcium sulfate or indicating-type silica gel desiccant.

6.3.3 *Analytical Balance*, wit a resolution of 0.1 mg and an uncertainty of 0.1 mg.

6.3.4 *Beakers*, 600 to 1000 ml, 150 ml.

6.3.5 *Hygrometer*, To measure the relative humidity of the laboratory environment.

6.3.6 *Temperature Gage*, To measure the temperature of the laboratory environment.

6.3.7 *Drying Oven*, Capable of maintaining temperature of 105 ± 2°C (221 ± 3.6°F).

6.3.8 *Separatory Funnel*, 1000 ml capacity.

6.3.9 *Hot Plate*, Heavy duty.

6.3.10 *Ribbed Watch Glasses.*

6.3.11 *Filtration Apparatus*, Includes suction flask , filter holder and vacuum pump.

6.3.12 *Rubber Policeman*, To aid in quantitative sample transfer.

6.4 Particle Size Distribution Apparatus

6.4.1 *Cascading Impactor*, capable of sampling in plume with minimum of 6 stages and detection range of 0.4 to 21 μm.

6.4.2 *Micro Balance*, with the sensitivity of 0.001 or 0.01 mg.

6.4.3 *Tweezers*, for handling substrates.

7. Reagents and Materials

7.1 Sampling Reagents and Materials

7.1.1 *Filter*, shall be made of glass fiber without organic binders, and shall exhibit at least 99.95 percent efficiency (0.05 percent penetration) on 0.3 micron dioctyl phthalate smoke particles. The filter efficiency tests shall be conducted in accordance with ASTM Standard Method D2986 - 71. Test data from the supplier's quality control program are sufficient for this purpose.

7.1.2 *Silica Gel*, indicating type, 6 to 16 mesh. Use new silica gel as received. If previously used, dry at 175°C (350°F) for 2 hours.

7.1.3 *Water*, deionized, distilled water to conform to ASTM specification D1193-99.

7.1.4 *Crushed Ice or Dry Ice pellets*, Used for impinger train ice bath.

7.2 Sample Recovery Reagents and Materials

7.2.1 *Acetone*, reagent grade with ≤ 0.001 percent residue, in glass bottles. Acetone from metal containers generally has a high residue bland and shall not be used. Sometimes, suppliers transfer acetone to glass bottles from metal containers. Thus, acetone blanks shall be run prior to field use and only acetone with low blank values (0.001 percent) shall be used. In no case shall a blank value be greater than 0.001 percent of the weight of acetone used be subtracted from the sample weight.

7.2.2 *Methylene Chloride/Dichloromethane ($MeCl_{2}$)*, Reagent grade with ≤ 0.001 percent residue.

7.3 Cascading Impactor Reagents and Materials

7.3.1 *Impactor Substrates*, mylar substrate.

8. Hazards

8.1 Review OSHA and MSDS guidelines before handling acetone and methylene chloride.

9. Preparation and Calibration

9.1 *Probe Nozzle*, Select a nozzle size based on the range of velocity heads encountered, so that it is not necessary to change the nozzle size to maintain isokinetic sampling rates. Do not change the nozzle size during the run. Choose the differential pressure gauge appropriate for the range of velocity heads encountered (see SCAQMD Method 2.1). Each probe nozzle must be calibrated before their use. Using a micrometer, measure the inside diameter of the nozzle to the nearest 0.025 mm (0.001 in.). Make three separate measurements using different diameters each time, and obtain the average of the measurements using the Nozzle Calibration Sheet (Form 1). The difference between the high and low numbers shall not exceed 0.1 mm (0.004 in.). When nozzles become nicked, dented, or corroded, they shall be reshaped, sharpened, and re-calibrated before use. Each nozzle shall be permanently and uniquely identified. Connect the nozzle to the probe liner with a leak-free fitting resistant to heat and chemicals.

9.2 *Pitot Tube*, If the pitot tube is placed in an interference-free arrangement with respect to the other probe assembly components, its baseline (isolated tube) coefficient shall be determined as outlined in SCAQMD Method 2.1.

9.3 *Temperature Gauges*, Use the procedure in SCAQMD Section 4.3 of Method 2 to calibrate in-stack temperature gauges. Dial thermometers, such as are used for the dry gas meter and condenser outlet, shall be calibrated against mercury-in-glass thermometers.

9.4 *Barometer*, Calibrate against a mercury barometer.

9.5 *Sampling Train*, All sampling train glassware shall be cleaned prior to *each* test with soap and tap water, water, and rinsed using tap water, water, acetone, and finally, methylene chloride.

9.6 *Cascading Impactor*, All internal surfaces of the impactor must be clean. Disassemble the impactor and wash each part in water with detergent or in alcohol. Alternatively, the parts can be cleaned in an ultrasonic bath. Rinse and dry completely. Hold stages up to a light to make sure all slots are free of foreign matter.

10. Procedures

10.1 Pretest Determination

10.1.1 Select the sampling site and the minimum number of sampling points according to SCAQMD Method 1.1. If it is not possible to follow Method 1.1, or more than one sample site must be tested, see SCAQMD Chapter X. Determine the stack pressure, temperature, and the range of velocity heads using SCAQMD Method 2.l.

10.1.2 Determine the moisture content, using SCAQMD Method 4.1 or its alternative, to make sampling rate settings.

10.1.3 Determine the stack gas dry molecular weight as described in SCAQMD Method 3.1. If integrated sampling (SCAQMD Method 3.1) is used for molecular weight determination, take the integrated bag sample throughout the total time of the particulate sample run, unless the effect on the velocity measurement and resulting stack flow rate calculation is less than 1 percent. In that case take the integrated sample immediately before, after, or for a shorter time during the particulate sample run.

10.1.4 Select a probe length suitable for sampling all traverse points. Consider sampling large stacks from opposite sides (four sampling port holes) to reduce probe lengths. Mark the probe with heat resistant tape or by some other method to denote the proper distance to insert the probe into the stack or duct for each sampling point.

10.1.5 Select a total sampling time equal to or greater than the minimum total sampling time specified in test procedures for the specific industry. The sampling time per point must not be less than 2 minutes and the total sample volume taken (corrected to standard conditions) must not be less than 30 ft^3.

NOTE 3—To avoid time-keeping errors, it is recommended that the number of minutes sampled at each point should be an integer or an integer plus one-half minute. The sampling time should be the same at each point. In some circumstances, e.g. batch cycles, it may be necessary to sample for shorter times at the traverse points, resulting in smaller gas sample volumes. In these cases, test two or more cycles.

10.1.6 Calibrate the metering system using Form 2. Dial in an orifice pressure using the course adjustment and pinpoint with the fine adjustment to 0.4 in. H_2O. Start a timer and note the initial reading on the gas meter. Allow the pump to operate for a minimum of 1 minute. At the end of the sampling, note the time and final gas meter reading. Calculate the K factors using the equation given in Form 2. Repeat the test for orifice pressures at 0.75 and 1.6 in. H_2O. The maximum allowable difference between any two K factors is 0.02.

NOTE 4—The orifice pressures during calibration may need to be varied depending on the pressures encountered during traverse sampling. The pump correction is only valid for orifice pressures between the calibrated range; therefore, the high and low orifice pressure many be adjusted to sandwich the sampling pressures.

10.2 Pretest Preparation

10.2.1 All equipment, including balances, oven temperature, glassware, and safety equipment should be checked for readiness before proceeding. Weigh several 200 to 300 g portions of silica gel in air-tight containers to the nearest 0.5 g. Record the total weight of the silica gel plus container, on each container. As an alternative, the silica gel may be weighed directly in its impinger or sampling holder just prior to train assembly.

10.2.2 Check filters visually against light for irregularities, flaws or pinhole leaks. Label filters of the proper diameter on the back side, near the edge using numbering machine ink. As an alternative, label the shipping containers (glass or plastic petri dishes) and keep the filters in these containers at all times except during sampling and weighing.

10.2.3 Desiccate the filter at 15 ± 5.6°C (60 ± 10°F) and ambient pressure for at least 24 hours. Weigh at intervals of at least 6 hours to a constant weight (i.e. 0.5 mg change from previous weighing); record each weight to the nearest 0.1 mg. During each weighing the filter must not be exposed to the laboratory atmosphere for a period greater than 2 minutes and a relative humidity above 50 percent. Alternatively, the filters may be oven dried at 105°C (220°F) for 2 to 3 hours, desiccated for 2 hours, and weighed.

10.2.4 During preparation and assembly of the sampling train, cover all openings wherever contamination can occur until just prior to assembly. Assemble the impingers in the tray as shown in Figure 1. Load each of the impingers with exactly 100 ml of water. Place approximately 200 to 300 g of silica gel in the fourth impinger and record its weight to the nearest 0.5 g. More silica gel may be used, but ensure that it is not entrained and carried out of the impinger during sampling.

10.2.5 If moisture content is to be determined gravimetrically, weigh each impinger plus its contents to the nearest 0.5 g and record the weights.

10.2.6 Using tweezers or clean disposable surgical gloves, place a weighed and identified filter in the filter holder. Be sure that the filter is properly centered and the gasket properly placed to prevent the sample gas stream from circumventing the filter. Check the filter for tears after assembly is completed.

10.2.7 When using a glass liner, install the selected nozzle using a Viton A 0-ring when stack temperatures are less than 260°C (500°F), and an asbestos string gasket when temperatures are higher. Teflon ferrules may also be used for temperatures less than 350°F. With metal liners, install the nozzle as above or by a leak-free direct mechanical connection. Use of stopcock grease is not recommended. Connect the impingers, and seal the train or its components for transport to the sampling site.

10.3 Cascading Impactor Setup

10.3.1 Pre-weigh all cascading impactor substrates and backup filters in a clean laboratory environment. Record the weights using a micro balance in Form 6. The substrates and filter should be equilibrated with the lab environment for approximately 24 hours at a relative humidity of 50 percent or less, before weighing.

10.3.2 Assemble the impactor with substrates according to manufacturer’s directions. Connect the tubing to the sampling pump and set the desired sampling flow rate on the pump. Record the flow rate and initial volume reading (if applicable) on Form 6. Turn on the pump when the test starts and note the time.

10.4 Pretest Leak Check

10.4.1 If a Viton A O-ring or other leak-free connection is used in assembling the probe nozzle to the probe liner, leak check the train at the sampling site by plugging the nozzle and drawing a 380 mm (15 in.) Hg vacuum. A lesser vacuum may be used if it is not exceeded during the test. The probe may be leak checked separately at a pressure equal to the stack pressure minus 25 mm (1 in.) Hg. Alternatively, the probe may be leak checked with the rest of the sampling train, at 380 mm (15 in.) Hg vacuum. A leakage rate in excess of either 4 percent of the average sampling rate or 0.02 cfm (0.00057 m^3/min), is unacceptable.

10.4.2 Start the pump with the bypass valve fully open and the coarse adjust valve completely closed. Partially open the coarse adjust valve and slowly close the bypass valve until the desired vacuum is reached. Do not reverse direction of bypass valve; this-will cause water to back up into the probe. If the desired vacuum is exceeded, either leak check at this higher vacuum or end the leak check as shown below and start over.

10.4.3 When the leak check is completed, slowly remove the plug from the inlet to the probe, and then turn off the vacuum pump. This prevents the water in the impingers from being forced backward into the filter holder and silica gel from being entrained into the third impinger.

10.4.4 Perform a leak check of the Pitot lines. (See SCAQMD Method 2.1).

10.5 Leak Check During Sampling Run

10.5.1 If a component change (e.g. filter assembly or impinger) becomes necessary during the sampling run, conduct a leak check immediately before the change is made. Use the pretest leak check procedure, but use a vacuum equal to or greater than the maximum value recorded up to that point in the test. If the leakage rate is not greater than either 0.02 cfm (0.00057 m^3/min) or 4 percent of the average sampling rate, the results are acceptable and no correction has to be applied to the total volume of dry gas metered. However, if the leakage rate exceeds either of these limits, the tester must either record the leakage rate and correct the sample volume as shown in SCAQMD Chapter X, Section 7, or void the sampling run immediately after component change.

10.6 Sampling Train Operation

10.6.1 During the sample run, maintain an isokinetic sampling rate within 10 percent of true isokinetic.

10.6.2 For each run, record the data required on the Traverse Source Test Data Sheet (Form 3). Be sure to record the initial dry gas meter reading. Record the dry gas meter readings at the beginning and end of each sampling time increment, when changes in flow rates are made, before and after each leak check, and when sampling is halted.

10.6.3 Record other data required by the sheet in Form 3 at least once for each sample point during each time increment. Take additional readings when significant changes (20 percent variation in velocity head readings) require adjustments in flow rate.

10.6.4 Level and zero the manometer and make periodic checks during the traverse because the manometer level and zero may drift due to vibrations and temperature changes.

10.6.5 Clean the portholes prior to the test run to minimize the chance of contamination. To begin sampling, remove the nozzle cap and verify that the Pitot tube and probe are properly positioned.

10.6.6 During the period before sampling, the nozzle can be pointed downstream. Position the nozzle at the first traverse point and rotate the nozzle until the tip is pointing directly into the gas stream before turning on the sampling pump. Immediately start the pump and adjust the flow to isokinetic conditions.

10.6.7 Use calculators or nomographs to determine correct adjustment of the isokinetic sampling rate. When the stack is under significant negative pressure (height of water in impinger stem), take care to close the coarse adjust valve before inserting the probe into the stack to prevent water from backing into the probe. If necessary, the pump may be turned on with the coarse adjust valve closed.

10.6.8 When the probe is in position, block off the openings around the probe and porthole to prevent flow disturbance and dilution of the gas stream.

10.6.9 Traverse the stack cross section. Be careful to avoid bumping the probe nozzle into the stack walls when sampling near the walls or when removing or inserting the probe through the portholes. This minimizes the chance of extracting stack deposits.

10.6.10 During the test run, periodically add ice to maintain a temperature less than 15°C (60°F) at the condenser/silica gel outlet. Also, periodically check the level and zero of the manometer. Note and investigate any changes in stack temperature or velocity pressure over those measured during previous tests or traverses. Changes can mean failure of sampling equipment or a change in process.

10.6.11 If the pressure drop of the filter becomes too high, making isokinetic sampling difficult to maintain, the filter may be replaced during a sample run. Use another complete filter assembly rather than attempting to change the filter itself. Before a new filter assembly is installed, conduct a leak check (see Section 10.4).

NOTE 5—The total particulate weight includes the summation of all filter assembly catches. Use a single train for the entire sample run, except when sampling is required in two or more ducts or at two or more locations within the same duct, or when equipment failure necessitates a change of trains. When two or more trains are used, separate analyses of each train must be performed.

10.6.12 At the end of the sample run, turn off the coarse adjust valve, remove the probe and nozzle from the stack, turn off the pump, record the final dry gas meter reading.

10.7 Cascading Impactor Post Test Procedure

10.7.1 After the sampling period, turn off the pump and record the elapsed time and final volume reading (if applicable). The final flow rate can be checked to insure that constant flow was maintained through the sampling period.

10.7.2 Return to the lab with the fully assembled impactor transported in the upright position and sealed on the inlet to prevent sample contamination.

10.8 Post Test Leak Check

10.8.1 A leak check is mandatory at the conclusion of each sampling run. Follow the procedures outlined in Section 10.4 at a vacuum equal to or greater than the maximum value reached during the sampling run. Compare the leakage rate to the limits indicated in Section 10.4 and follow the procedure described there.

10.8.2 Leak check Pitot lines as described in SCAQMD Method 2.1. The lines must pass this leak check to validate the velocity head data.

10.8.3 Perform a meter calibration check as described in Section 10.1.6.

10.9 Calculation of Percent Isokinetics

10.9.1 Calculate percent isokinetics, using the equations shown on the Source Test Calculation Sheet (Form 4), to determine whether the run was valid or other test run should be made.

10.10 Sample Handling

10.10.1 Allow the probe to cool. When the probe can be safely handled, wipe off all external particulate matter near the tip of the probe nozzle and place a cap over it to prevent losing or gaining particulate matter. Do not cap off the probe tip tightly while the sampling train is cooling down. This would create a vacuum in the probe, drawing water from the impingers into the probe.

10.10.2 Inspect the train for general condition. Note if the silica gel is completely expended, and if the train or its components are sealed. Note any unusual conditions that may affect results, including torn filters, cloudiness in the impinger liquids, etc.

10.10.3 Before moving the sample train to the clean-up site, remove the probe from the sample-train, and cap the open outlets of the probe. Be careful not to lose any condensate that might be present. Remove the umbilical cord from the last impinger and cap the impinger. If a flexible line is used between the first impinger and the probe, disconnect the line at the probe and let any condensed water or liquid drain into the impingers. Cap off the open inlet of the flexible line opening. Either ground glass stoppers, plastic caps, or serum caps may be used to close these openings.

10.10.4 Transfer the probe and filter-impinger assembly to the clean-up area. This area should be clean and protected from the wind to reduce chances of contaminating or losing the sample. It is recommended that sample recovery be performed in a controlled laboratory environment.

10.11 Sample Recovery

10.11.1 Filter

10.11.1.1 Working in an area that is protected from the turbulent air movement and free from dust, disconnect the filter holder from the rest of the train. Carefully remove the filter from the filter holder and place it in its identified petri dish container. Use a pair of tweezers and/or clean disposable surgical gloves to handle the filter. If it is necessary to fold the filter, fold the particulate cake to the inside.

10.11.1.2 Carefully transfer to the petri dish any particulate matter and/or filter fibers which adhere to the filter holder gasket by using a dry nylon bristle brush and/or a sharp-edged blade. Seal the container.

10.11.2 Probe and Nozzle

10.11.2.1 Wipe the connection of the probe and train, and disconnect the probe from the train. During the probe and nozzle recovery, keep the remainder of the train sealed to prevent any contamination from occurring. Wipe down the outside of the probe and nozzle.

10.11.2.2 Taking care to see that dust on the outside of the probe or other exterior surfaces does not get into the sample, quantitatively recover particulate matter or any condensate from the probe nozzle, probe fitting, and probe liner by washing these components with water and placing the wash in a sample container.

10.11.2.3 Carefully remove the probe nozzle and clean the inside surface by rinsing with water from a wash bottle and brushing with a Nylon bristle brush. Brush until the rinse shows no visible particles, then make a final rinse-of the inside surface with water. Similarly, brush and rinse the inside parts of the Swagelok fitting with water until no visible particles remain.

10.11.2.4 Rinse the probe liner with water by tilting and rotating the probe while squirting water into its upper end so that all inside surfaces are wetted. Let the water drain from the lower end into the sample container. A glass or polyethylene funnel may be used to transfer liquid washes to the container.

10.11.2.5 Follow the water rinse with a probe brush. Hold the probe in an inclined position and squirt water into the upper end as the probe brush is being pushed with a twisting action through the probe. Hold a sample container underneath the lower end of the probe and catch any water and particulate matter which is brushed from the probe. Run the brush through the probe three or more times until no visible particulate matter is carried out with the water or until none remains in the probe liner on visual inspection.

10.11.2.6 With stainless steel or other metal probes, run the brush through in the above prescribed manner at least six times, since metal probes have small crevices in which particulate matter can be entrapped. Rinse the brush and quantitatively collect these washings in the sample container. After the brushing, make a final rinse of the probe.

10.11.2.7 To reduce sample losses, it is recommend that two people clean the probe. Between sampling runs, keep brushes clean and protected from contamination.

10.11.2.8 If the sample is recovered in the field, tighten the sample container lid and mark the fluid level to indicated if leakage has occurred during transport. Label the container to clearly identify its contents.

10.11.3 Impinger Catch

10.11.3.1 Wipe any dust, grit or water from the outside of the impingers, especially near the impinger joint. Carefully disconnect the impingers.

10.11.3.2 Weigh the impingers plus content to the nearest 0.5 g and record the weights. Transfer the catch to a sample container. Clean all surfaces by rubbing them with a Nylon bristle brush and rinsing with water three times or more if necessary to remove visible particulates. Make a final rinse of each component and the brush.

10.11.3.3 If this recovery is performed in the field, tighten the sample container lid and mark the fluid level to indicate if leakage has occurred during transport. Label the container to clearly identify its contents.

10.11.4 Silica Gel, Transfer the silica gel to its container and tighten the lid. Alternatively, weigh the impinger plus content to the nearest 0.5 g and record this weight, or seal the impinger for return to the laboratory.

10.11.5 Container Recovery,

10.11.5.1 If the sample has been recovered in the field, check all the sample containers to ensure that no sample was contaminated or lost during transport.

10.11.5.2 For a liquid catch, note the liquid level in the container and determine if noticeable leakage has occurred. If so, void the entire sample. Wipe the cap area and transfer the sample to a beaker. Carefully rinse the cap and container into the beaker, tilting the container and using a brush if necessary to dislodge particulate matter. Record the total volume to the nearest 10 ml, and proceed with the analysis. Combine the probe and impinger catches. Note whether the silica gel, impinger, or container was properly sealed; weigh and record to the nearest 0.5 g.

10.12 Analysis

10.12.1 Filter Catch

10.12.1.1 Leave the contents in the shipping container or transfer the filter and any loose particulate from the sample container to a tared glass weighing dish.

10.12.1.2 Desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate.

10.12.1.3 Weigh to a constant weight and report the results to the nearest 0.1 mg. For this method, the term "constant weight" means a difference of no more than 0.5 mg or 1 percent of total weight less tare weight, whichever is greater, between two consecutive weighings, with no less than 6 hours of desiccation time between weighings.

10.12.1.4 Alternatively, the sample may be oven-dried at 105°C (220°F) for 2 to 3 hours, cooled in a desiccator, and weighed to a constant weight.

10.12.2 Probe and Impinger Catch - Insoluble Particulates

10.12.2.1 If organic extraction is to be performed, first filter the sample through a tared fiberglass filter dried at 105°C (220°F). This prevents any insolubles from interfering with the organic extraction.

10.12.2.2 Rinse the filter and insoluble catch using dichloromethane and combine this rinse with the dichloromethane extract described in the next section.

10.12.2.3 Dry the fiberglass filter at 105°C (220°F) and report as "Insoluble Particulate".

10.12.3 Probe and Impinger Catch - Organic Extraction

10.12.3.1 Transfer the aqueous filtrate from Section 10.12.2 to a separatory funnel.

10.12.3.2 Extract the aqueous catch five times with 25 ml portions of dichloromethane. Each time, extract for 30 seconds with vigorous shaking, then allow the layers to separate. This may take up to 15 minutes due to emulsion formation. When using dichloromethane, use gloves and work in a hood.

10.12.3.4 Drain the dichloromethane layers into a tared 150 ml beaker. Save the aqueous layer for use in Section 10.12.4.

10.12.3.5 Evaporate the organic extract under a stream of clean filtered air at room temperature in a hood. Place in a desiccator overnight.

10.12.3.6 Weigh the extract residue to the nearest 0.1 mg. Record the gross and tared weights and report the net weight as “Solvent Extract”.

10.12.4 Probe and Impinger Catch - Soluble Residue

10.12.4.1 Quantitatively transfer the aqueous catch to a beaker.

10.12.4.2 If solvent extraction has been performed, warm the sample on a hot plate, being careful to prevent any residual solvent from causing the sample to “bump”. Use a ribbed watch glass to cover the beaker. This will allow scrubbing of the beaker walls and protect the sample from contamination. Concentrate the sample to about 50 ml.

10.12.4.3 Quantitatively transfer the aqueous concentrate to a tared 150 ml beaker and evaporate in an oven at 105°C (220°F) to dryness.

10.12.4.4 Weigh the residue to constant weight, to the nearest 0.1 mg, and record the weight. Desiccate the sample for 6 hours and reweigh the sample. Repeat until the weight changes less than 0.5 mg between weighings.

10.12.4.5 Add the insoluble and soluble weights from Sections 10.12.2 and 10.12.4 and report as "Impinger Catch". Do not include the solvent extract.

10.12.5 Cascading Impactor Substrates - Disassemble the stages and remove the collection substrates using a tweezers. Maintain their proper identification while weighing and recording the mass gains. Reduce the data according to Section 11.2.3.

11. Calculation and Report

11.1 *Particulate Matter*

11.1.1 Nozzle Calibration Sheet (Form 1)—Calculate and report the average nozzle diameter with the following relationship:

$$D_{ave} = \frac{D_1 + D_2 + D_3}{3}$$

where:

D_{ave} = average nozzle diameter,

D_1, D_2, D_3 = nozzle diameter measured at different locations.

11.1.2 Meter Calibration Sheet (Form 2)—Calculate and report the pump correction factor (K-factor) with the following relationship:

$$K^* = \frac{60 \times B}{C \times \sqrt{A}}$$

where:

K^* = pump correction factor (K - factor)

A = orifice pressure (in H_2O)

B = metered volume (ft^3)

C = time (sec)

11.2 *Cascading Impactor Particle Size Distribution*:

11.2.1 Make sure all information is completed in Form 6. Use additional text to describe any event encountered during the sampling or transport that may facilitate the audience's interpretation of the test results.

11.2.2 Confirm that the cascading impactor conformed to all of the specifications mandated by the manufacturer. Describe any deviations from those specifications.

11.2.3 Calculate the percent weight gain of substrate for each stage and backup filter as follows:

$$\% \text{ Ws} = \frac{\mathrm{W}_f - W_i}{\mathrm{W}_t} \times 100\ \%$$

where:

$\%W_s$= Percent weight gain of substrate
W_f = final substrate weight (mg)
W_i = initial substrate weight (mg)
W_t = total weight gain of all stages and back filter

$$= \sum_{j=1}^{N} \left[\mathrm{W}_f - \mathrm{W}_i \right]_j$$

where:
j = filter stage number
N = total number stage (including backup filter)

11.2.4 Present the particle size distribution on a log graph. Plot the particle size along the x-axis and the % weight gain on the y-axis.

12. Precision and Bias

12.1 Precision
12.1.1 Repeatability (Within Laboratory, Same Operators and Equipment):
12.1.1.1 For emission concentration, the percentage uncertainty in each result has been specified to be no greater than ±10% based on at least three test runs.
12.1.1.2 The repeatability of the particle size distribution is being determined.
12.1.2 Reproducibility (Multiple Laboratories)—the interlaboratory precision of the procedure in these test methods for measuring each reported parameter is being determined.
12.2 Bias—No statement can be made concerning the bias of the procedures in these test methods because there are no accepted reference values for the parameters reported.

ANNEX
(MANDATORY INFORMATION)

Test No. : ____________________ Test Date : ____________________

Process Type: ____________________ Sampling Location : ____________________

Input by : ____________________ Sampling Train : ____________________

NOZZLE CALIBRATION SHEET

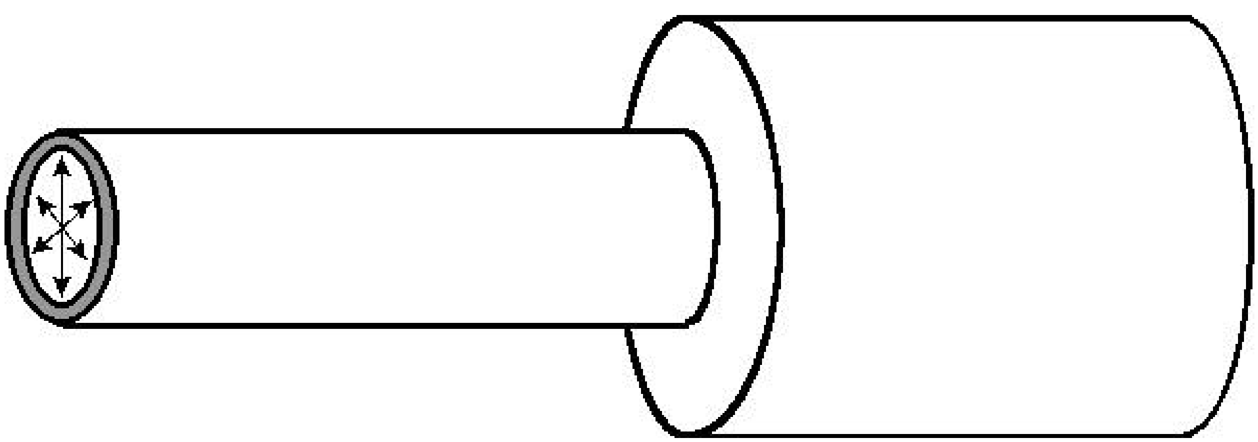
Nozzle Identification Number	D_1 mm (in)	D_2 mm (in)	D_3 mm (in)	DD mm (in)	D_{ave} mm (in)

where

$D_{1,2,3}$ = nozzle diameter measured on a different diameter (mm or in) as shown below.
Tolerence within 0.25 mm (0.001 in).

DD = Maximum difference in any two measurements (mm or in).
Tolerence within 0.1 mm (0.004 in).

D_{ave} = Average of D_1, D_2 and D_3.



Form 1: Nozzle Calibration Sheet

Test No. : ____________________ Test Date : ____________________

Process Type: ____________________ Sampling Location : ____________________

Input by : ____________________ Sampling Train : ____________________

METER CALIBRATION SHEET

PRETEST Date: ____________ Time: ____________

Orifice Pressure A (in H_2O)	Metered Volume B (ft^3)	Time C (seconds)	K*
0.4			
0.75			
1.6			

Performed by: ________ Average K* ____________

POST TEST Date: ____________ Time: ____________

Orifice Pressure A (in H_2O)	Metered Volume B (ft^3)	Time C (seconds)	K*
0.4			
0.75			
1.6			

Performed by: ________ Average K* ____________

$$K^* = \frac{60 \times B}{C \times \sqrt{A}}$$

* Maximum allowable difference in any two measurements of K is 0.02.

Form 2: Meter Calibration Sheet

Test No. : ____________________ Test Date : ____________________

Process Type: ____________________ Sampling Location : ____________________

Input by : ____________________ Sampling Train : ____________________

TRAVERSE SOURCE TEST DATA SHEET

Pre-test Velocity Leak Check: ____________________

Post-Test Velocity Leak Check: ____________________

Stack Diameter: ____________________

Nozzle Diameter: ____________________

Nozzle Cross Area: ____________________

Barometric Pressure: ____________________

Static Pressure in Stack: ____________________

Gas Meter Correction Factor: ____________________

Pitot Factor: ____________________

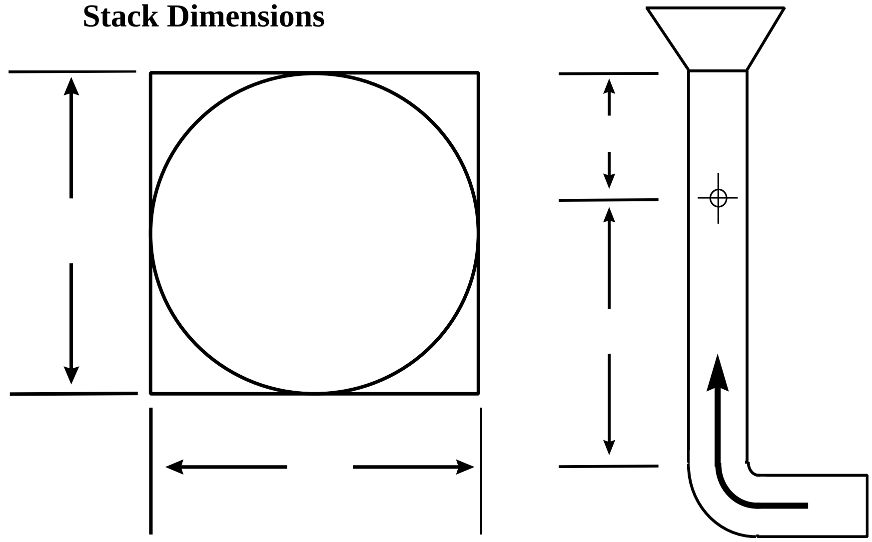
K Factor: ____________________

% of Moisture: ____________________

Sampling Time: ____________________

Time (min)	Traverse Point	Gas Meter Reading	Vel. Head (" water)	Temp. (°F)	Calc. Vel (fps)	Sampling Rate (cfm)	Theo. Orif P (" water)	Act. Orif P (" water)	Meter Temp. In (°F)	Meter Temp. Out (°F)

Stack Dimensions



Form 3: Traverse Source Test Data Sheet

Test No. : ______ Test Date : ______

Process Type: ______ Sampling Location : ______

Input by : ______ Sampling Train : ______

SOURCE TEST CALCULATION SHEET (VELOCITY)

SUMMARY

A. Average Traverse Velocity (Pre test).. ______ fps

B. Average Reference Point Velocity (Pre-Test).................... ______ fps

C. Average Traverse Velocity (During Test)................. ______ fps

D. Gas Meter Temperature (Use 60 °F for Temp Comp. Meters)................................... ______ °F

E. Gas Meter Correction Factor...................................... ______

F. Average Stack Temp. : ______ °F

G. Stack Cross Sect. Area : ______ ft^2

H. Barometric Pressure : ______ in HgA

I. Gas Meter Pressure : ______ in HgA

J. Total Stack Pressure : ______ in HgA

K. Pitot Correction Factor : ______

L. Sampling Time : ______ min

M. Nozzle Cross Sect. Area : ______ ft^2

N. Net Sample Collection : ______ mg

O. Net Solid Collection : ______ mg

P. Water Vapor Condensed : ______ ml

Q. Gas Volume Metered : ______ dcf

R. Corrected Gas Volume .... ______ dscf

PERCENT MOISTURE DENSITY

S. Percent Water Vapor in Gas Sample ______ %

T. Average Molecular Weight (Wet):

Component	Vol. Fract. x	Moisture fract. x	Molecular Wt. =	Wt/ Mole
Water		1.00	18	______
Carbon Dioxide	(dry basis)		44	______
Carbon Monoxide	(dry basis)		28	______
Oxygen	(dry basis)		32	______
Nitrogen & Inerts	(dry basis)		28.2	______
			SUM =	

FLOW RATE

U. Gas Density Correction Factor $\left[\sqrt{\frac{28.95}{T}}\right]$ .... ______

V. Flue Correction Factor $\left[\frac{A}{B}\right]$ .... ______

W. Velocity Pressure Correction Factor $\left[\sqrt{\frac{29.92}{J}}\right]$ .... ______

X. Corrected Velocity $[C \times K \times U \times V \times W]$ .... ______ fps

Y. Flow Rate $[X \times G \times 60]$ .... ______ cfm

Z. Flow Rate (Standard) $\left[Y \times \frac{J}{29.92} \times \frac{520}{(460 + F)}\right]$ .... ______ scfm

AA. Flow Rate (Dry Standard) $\left[Z \times \left(1 - \frac{S}{100}\right)\right]$ .... ______ dscfm

SAMPLING CONCENTRATION/ EMISSION RATE

BB. Sample Concentration $\left[0.01543 \times \frac{N}{R}\right]$ .... ______ gr/ dscf

CC. Sample Concentration $\left[54{,}143 \times \frac{BB}{MolecularWt}\right]$ .... ______ ppm (dry)

DD. Sample Emission Rate $[0.00857 \times AA \times BB]$ .... ______ lb/ hr

EE. Solid Emission Rate $\left[\frac{0.0001322 \times O \times AA}{R}\right]$ .... ______ lb/ hr

FF. Isokinetic Sampling Rate $\left[\frac{G \times R \times V \times 100}{L \times M \times AA}\right]$ .... ______ %

Form 4: Source Test Calculation Sheet

Test No. :		Test Date :	
Process Type:		Sampling Location :	
Input by :		Sampling Train :	

PARTICULATE MATTER CALCULATION SHEET

LAB ANALYSIS

Moisture Gain:		g
Organic Extract:		mg
Insoluable:		mg
Soluable:		mg
Filter:		mg

Form 5: Particulate Matter Calculation Sheet

Test No. :		Test Date :	
Process Type:		Sampling Location :	
Input by :		Sampling Train :	

IMPACTOR DATA SHEET

Initial Volume:		(ft^3)	Initial Time:		(min)
Final Volume:		(ft^3)	Final Time:		(min)
Total Volume:		(ft^3)	Total Time:		(min)

Stage Number	Stage Size (µm)	Initial Weight (mg)	Final Weight (mg)	Weight Gain (mg)	% on Stage (%)
1					
2					
3					
4					
5					
6					
7					
8					
Backup					
		Sum			

Form 6: Impactor Data Sheet

APPENDIX III

Advisory Board Meeting #27 Presentation

Development and Scope of STM for

Determining Particulate Matter and Condensable Gas Emissions from Commercial Cooking Processes

SCOPE FOR TRANSITION PIER PROJECT

	STATUS
Setup and Calibrate Instrumentation	complete
Measure Emissions for Various Processes	complete
Commercial Kitchen Emission Workshop	complete
Evaluate Filter Efficiency (preliminary)	in progress
Draft Emission Standard Test Method (STM)	in progress
Final Report	in progress

STM CONSIDERATIONS

Survey Existing Work

Be Specific to Commercial Cooking Process

Incorporate Experience from Testing

Draft the Test Method

Feedback from the Industry and Other Research Labs

Submit to ASTM for Ratification

EXISTING PM TEST METHODS

South Coast Air Quality Management District
Method 5.0, 5.1

Environmental Protection Agency
Method 5, 5G, 5H, 17, 201, 201A, 202

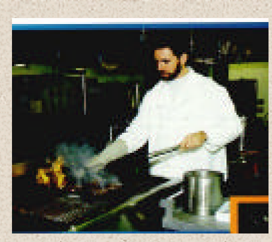
Underwriters Laboratories
Standard 197

EMISSION TEST METHOD SCOPE

Particulate Matter
- Solid PM
- Condensable PM

Particulate Size Distribution
- In-Plume
- In-Duct

WHAT CHANGED?



TITLE CHANGE

EPA 5.0

Determination of Particulate Matter Emissions From Stationary Source

SCAQMD 5.1

Determination of Particulate Matter Emissions From Stationary Sources Using a Wet Impingement Train

ASTM DRAFT

Standard Test Method for Determining Particulate Matter and Condensable Gas Emissions from Commercial Cooking Processes

ANALYSIS CHANGES

SCAQMD

Includes Sulfate and Acid Analysis

(typical for coal burning power plants and chemical processes)

ASTM

Omit Sulfate and Acid Analysis

ADDITIONAL PROCEDURE

SCAQMD/ EPA

No Size Distribution Procedure

ASTM

Include Size Distribution Procedure

CALIBRATION TEST CHANGE

SCAQMD/ EPA

Gas Metering System Calibration

(tedious and involved)

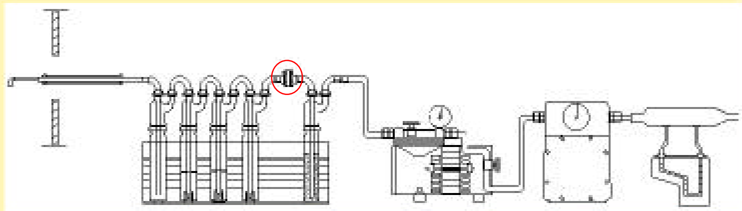
ASTM

K-Factor Determination

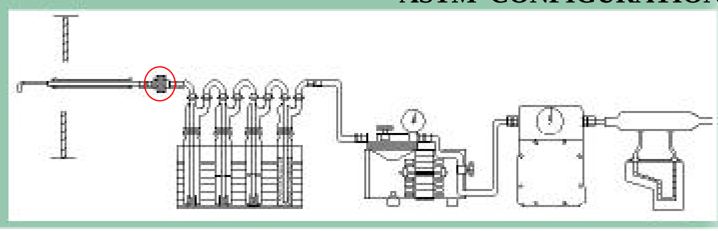
(viable alternative)

IMPINGER TRAIN CHANGES

SCAQMD CONFIGURATION



ASTM CONFIGURATION



POSSIBLE OBSTACLES

Referencing SCAQMD Procedures

- **Determination of Stack Gas Velocity and Volumetric Flow Rate.**
-
- **Sample and Velocity Traverse for Stationary Sources .**
-
- **Stack Gas Density and Moisture**

POSSIBLE OBSTACLES

Size Distribution Impactor Procedures

- Several Manufacturers.
-
- Keep Procedures Open-Ended.

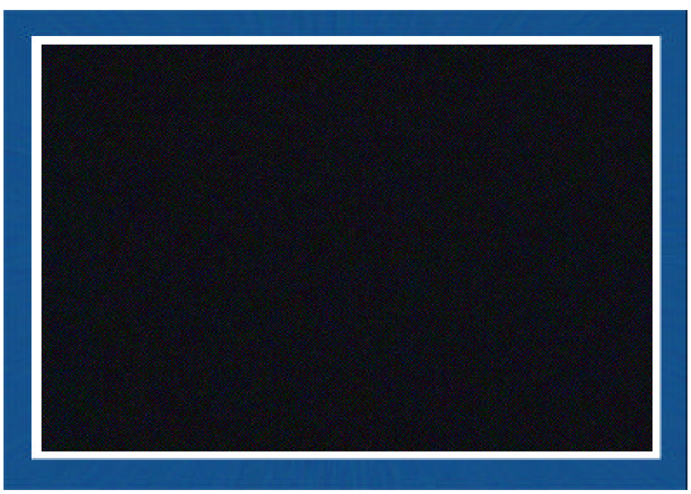
TEST METHOD PROCEDURAL OUTLINE

1. Pretest Determinations
2. Pretest Preparation
3. Impactor Setup
4. Pretest Test Leak Check
5. Leak Check During Sampling Run
6. Sampling Train Operation
7. Impactor Post Test
8. Post Test Leak Check
9. Calculation of Isokinetics
10. Sample Recovery
11. Sample Analysis
12. Calculation and Reporting

PROCEDURE TIME REQUIREMENT

1. Pretest Determinations	One time deal
2. Pretest Preparation 3. Impactor Setup 4. Pretest Test Leak Check 5. Leak Check During Sampling Run	2-4 hours
6. Sampling Train Operation	1-2 hours
7. Impactor Post Test 8. Post Test Leak Check 9. Calculation of Isokinetics 10. Sample Recovery 11. Sample Analysis 12. Calculation and Reporting	14-24 hours
TOTAL TURN-AROUND TIME	17-30 hours

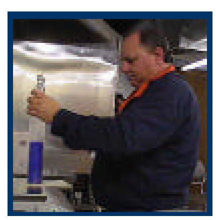
EMISSION TEST VIDEO CLIP



..... And Now

the Preliminary Test Data....

Determining Particulate Emissions
and Size Distribution from
Commercial Kitchens



Preliminary Data

OVERVIEW

- Test Design and Setup
- Test Factors
- Results
- Conclusions

TEST DESIGN AND SETUP

- Hood
- Duct
- Particulate matter sampling train

TEST DESIGN AND SETUP

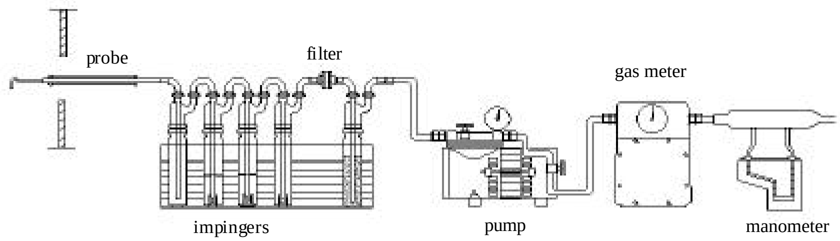
Hood
to contain and totally capture particulate emissions

TEST DESIGN AND SETUP

Duct
For isokinetics at 200 cfm

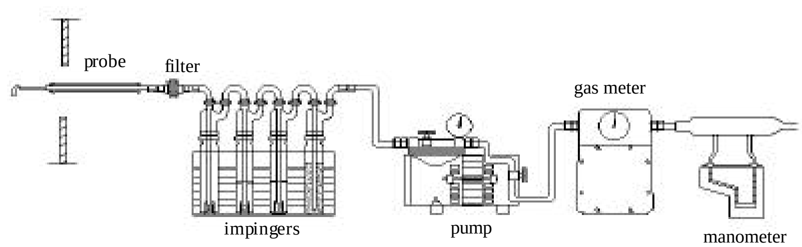
TEST DESIGN AND SETUP

SCAQMD Impinger Train



TEST DESIGN AND SETUP

ASTM Proposed Impinger Train



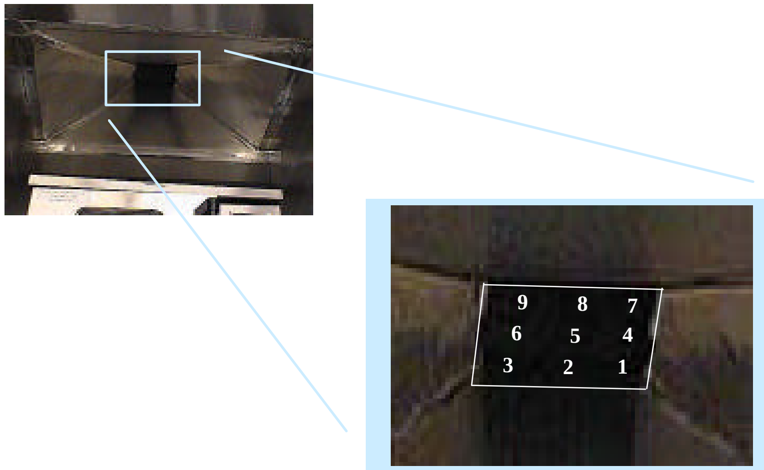
TEST FACTORS

- Appliance
- Test conditions
- Product
- Procedures
- Sampling methods

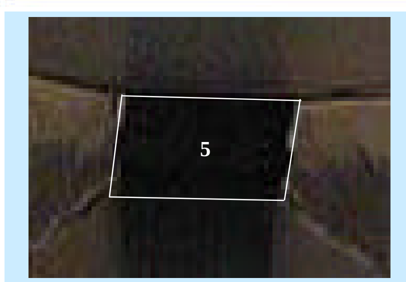
PROCEDURES

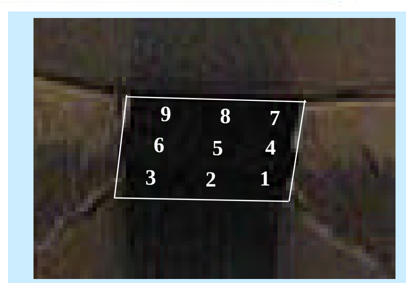
1. Pretest Determinations
2. Pretest Preparation
3. Impactor Setup
4. Pretest Test Leak Check
5. Leak Check During Sampling Run
6. Sampling Train Operation
7. Impactor Post Test
8. Post Test Leak Check
9. Calculation of Isokinetics
10. Sample Recovery
11. Sample Analysis
12. Calculation and Reporting

SAMPLING LOCATIONS



SAMPLING LOCATION RESULTS





Single Point Sampling

0.7 mg/m^3
5.9 mg/m^3
29.7 mg/m^3

Traversed Sampling

21.5 mg/m^3
19.3 mg/m^3

TEST RESULTS

Appliance	Product	Emissions (mg/m^3)
1/2 Size Bakery Oven	Cinnamon Rolls	12.1
Halogen Lamp Oven	Pepperoni Pizza	17.8
Specialized Oven (no filter)	Pepperoni Pizza	24.9
Specialized Oven (with filter)	Pepperoni Pizza	11.6

Ventilation flow rate = 200 cfm

CONCLUSIONS

- Major technical obstacles overcome
- Upgrade test facility
- Continue to increase emission database

APPENDIX IV

Advisory Board Meeting #28 Presentation

[redacted]

Refining Test Procedures
and Defining Codes

Advisory Group Meeting #28
November 4 & 5, 1999

[redacted]

- Mechanical codes are inconsistent and vague
- No standard test for unhooded equipment
- Emission limit of 5 mg/m^3 for ductless hoods (UL 197) may be recognized by the authority having jurisdiction

[redacted]

- 5 mg/m^3 is a concentration, not an absolute quantity of grease (e.g., lb/h or lb/lb food cooked)

- For example, 8 mg/m^3 in exhaust flow of 400 cfm becomes 4 mg/m^3 if exhaust rate is increased to 800 cfm

- But, the same quantity of grease is produced!

[redacted]

Research & Code Change Needed

- Criteria for when an appliance does not need a hood (either Type I or Type II).

- Refine test method (UL 197) for re-circulating (ductless) hood systems.

- Work with IMC, NFPA, UL to adopt new criteria.

[redacted]

UL 197

Evaluates re-circulating hood
Employs EPA Method 202
Measure condensable organic gases (grease)

Maximum product capacity
1-point, continuous, 8-hour test

5 mg/m^3 PASS/FAIL criteria

[redacted]

Replicates Are Mandatory

UL 197

Single 8-hr test.

Suggestion

Triplicate tests with ~ 1.5 - 2 hours duration.

[redacted]

Product / Load Specifications

UL 197
  Load capacity = "...maximum capacity..."
  Product specification
    ie. Hamburger patties 70/30, 4 inch, etc…

Suggestion
  Use existing ASTM test method for product specifications, handling and loading procedures.

[redacted]

Pass / Fail Criteria

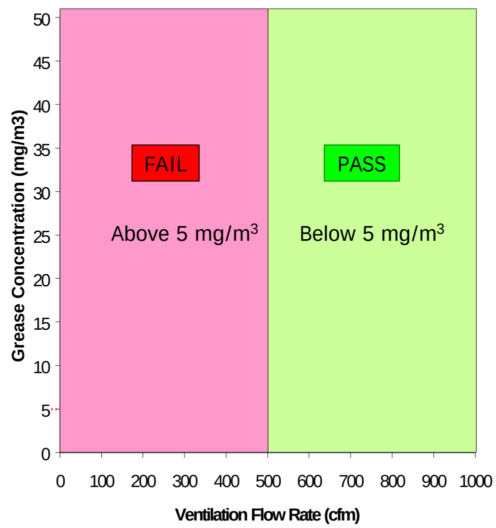
UL 197
  5 mg/m^3 (pass/fail Criteria).
  Not absolute

Suggestion
  Peak grease production rate (lb/h).
  Absolute

[redacted]

UL 197
5 mg/m³ Concentration Criteria
Ventilation Flow Rate Versus
Grease Concentration

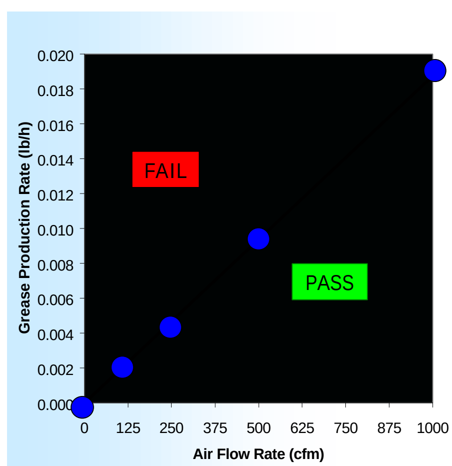
Grease Production Rate (lb/h)	Ventilation Flow Rate (cfm)	Grease Concen-tration (mg/m^3)
0.010	50	53.4
0.010	125	21.4
0.010	250	10.7
0.010	500	5.3
0.010	1000	2.7
	X	Y



[redacted]

Suggested Emission Rate Criteria:
Air Flow Rate Versus
Grease Production Rate

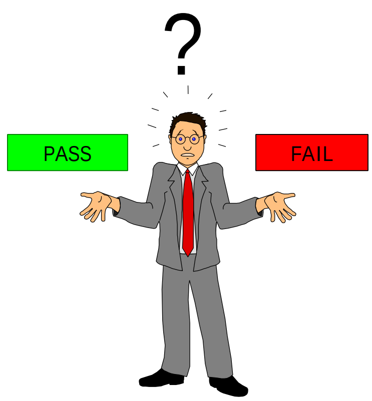
Grease Concen-tration (mg/m^3)	Air Flow Rate (cfm)	Grease Production Rate (lb/h)
5	0	0
5	125	0.0023
5	250	0.0047
5	500	0.0094
5	1000	0.0187
	X	Y



[redacted]

So what is the emission criteria for ductless hood ?

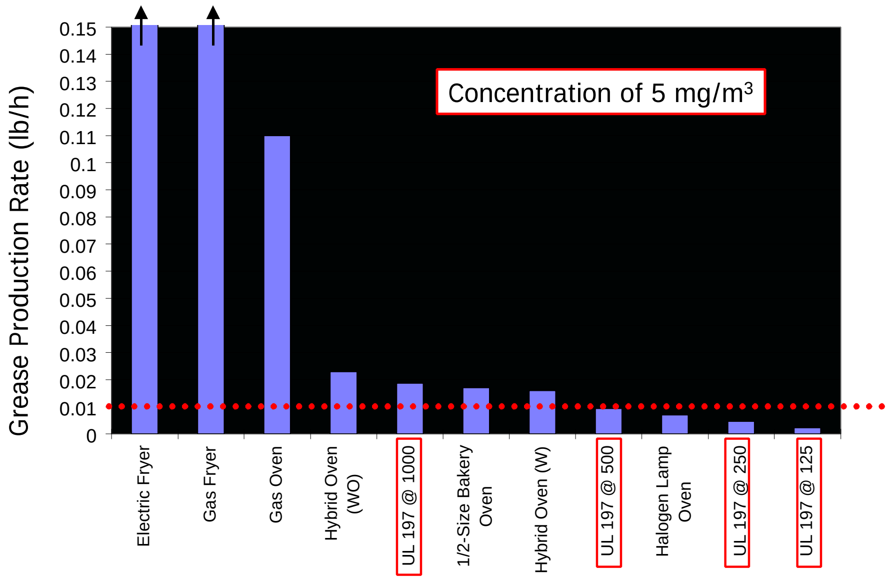
Grease Production Rate (lb/h)
1000
100
10
1
0.1
0.01
0.001
0.0001



[redacted]

Appliance Food Product	Rated Input	Cooking Rate (lb food cooked/h)	Emission Factor (lb emission/ 1000 lb food cooked)	Grease Production Rate (lb emissions/h)	
Gas Broiler 20% fat, frozen 1/3 pounder	108 kBtu/h	28.59	50.28	1.44	University of Minnesota
Electric Broiler 20% fat, frozen 1/3 pounder	10.8 (208V)	23.96	33.42	0.80	
3-ft Gas Griddle 20% fat frozen quarter pounder	80 kBtu/h	32	16.35	0.52	
3-ft Electric Griddle 20% fat frozen quarter pounder	10.7 kW (208V)	30	14.91	0.45	
Gas Range spaghetti with pork sausage	120 kBtu/h	53.44	6.69	0.36	
Electric Oven 8.2% fat, sausage pizza	11 kW (208V)	88.76	2.66	0.24	
Electric Range spaghetti with pork sausage	12 kW (208V)	53.44	4.28	0.23	
Electric Fryer par-cooked shoestring potatoes	12.9 kW (208V)	60	3.52	0.21	
Gas Fryer par-cooked shoestring potatoes	80 kBtu/h	66.45	2.86	0.19	
Gas Oven 8.2% fat, sausage pizza	55 kBtu/h	83.83	1.27	0.11	
Hybrid Oven WO Filter pepperoni pizza	10.8 kW (208V)	52.5	0.44	0.023	FSTC
1/2-Size Bakery Oven cinnamon rolls	8 kW (208V)	22.5	0.73	0.017	
Hybrid Oven WITH Filter pepperoni pizza	10.8 kW (208V)	52.5	0.31	0.016	
Halogen Lamp Oven pepperoni pizza	11.9 kW (208V)	33.6	0.22	0.007	

[redacted]



[redacted]

Suggestion

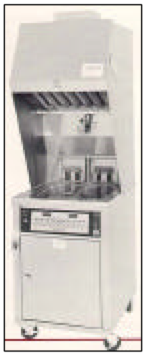
Peak grease production rate of **0.01 lb/h**.

Normalize

0.01 lb/h ... per appliance? ...per hood?

[redacted]

Not all ductless hoods are alike



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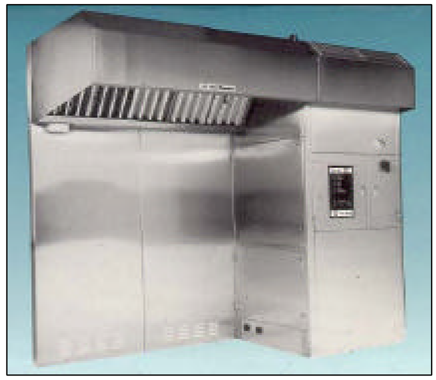


[redacted]

Normalizing Grease Production Rate

Assume

A typical ductless hood active cooking length: 1.5-linear foot

0.01 lb/h of grease production limit

Then,

0.007 lb/h per linear foot.

$$= \frac{0.01 \text{ lb/h}}{1.5 \text{ ft}}$$

$$= 0.007 \text{ lb/h per foot}$$

[redacted]

What About Unhooded Equipment?

Peak grease production rate of **0.01 lb/h** per appliance

[redacted]

Suggested Criteria

Unhooded Appliances
Peak grease production rate of **0.01 lb/h** per appliance

Re-circulating Hood
0.007 lb/h per foot of active appliance length

APPENDIX V

Emissions Workshop Agenda and Overview Presentation

Pacific Gas and Electric Company

FOOD SERVICE TECHNOLOGY CENTER

Co-Sponsored by the California Energy Commission.

INVITES YOU TO A

COMMERCIAL COOKING EQUIPMENT SEMINAR: PRACTICAL LIMITS IN EMISSIONS AND ODOR CONTROL

PG&E's Food Service Technology Center has been dedicated to establishing comprehensive performance test methods for benchmarking equipment used in food service facilities. The leader in independent commercial appliance testing, PG&E measures energy consumption of gas and electric equipment under both laboratory and real-world conditions. Directly related to the performance and energy efficiency of commercial cooking equipment is the associated exhaust ventilation system. The effluent from char broiling has become a focus for air quality regulations in California. Other cooking processes—wood-fired cooking equipment—have been identified as major sources of odor pollution. This seminar presents options for reducing cooking emissions based on research and real-world experiences.

- ♦ New Emission Legislation in California
- ♦ Emission Measurement Protocols
- ♦ Characterization of Effluent from Cooking Processes
- ♦ Efficiency of Emission Control Equipment
- ♦ Case Study Experiences

WHEN:
MONDAY, FEBRUARY 22ND
1:00 - 5:00 P.M.

COST:
NO CHARGE

WHERE:
PG&E ENERGY CENTER
851 HOWARD STREET
(BETWEEN 4TH AND 5TH STREETS)
SAN FRANCISCO, CA
415-973-7268

To register, please contact Cathy Cesio at 925-866-5706, fax this form to 925-866-2864, or register on-line at http://www.pge.com/fstc. Registration deadline is February 17, 1999.

Name: ______________________________

Title: ______________________________

Company: ______________________________

Mailing Address: ______________________________

____

Phone: ______________________________

Fax: ______________________________

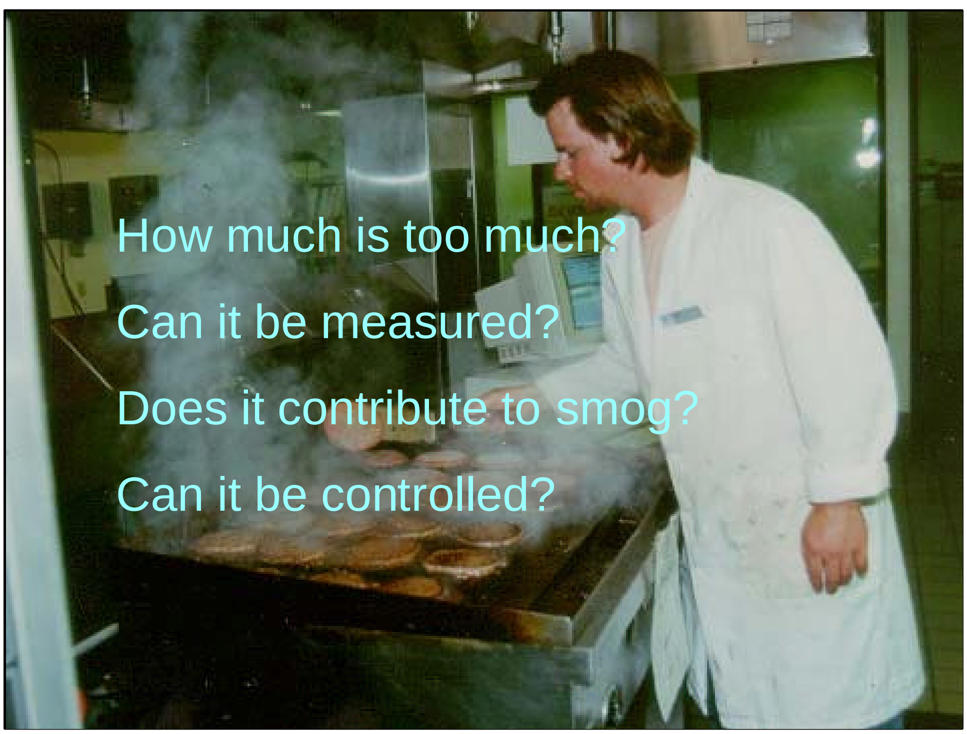
PG&E Food Service Technology Center

www.pge.com/fstc

Commercial Cooking Equipment: Practical Limits in Emission and Odor Control
Monday, February 22, 1999

1:00	Welcome and Introduction	Richard Young *Food Service Technology Center*
1:15	New Restaurant Rule in California • Cooking contribution to smog! • SCAQMD Legislative focus • Technical perspective	Don Fisher *Food Service Technology Center*
1:45	Measurement of Cooking Emissions • TPM and VOC • Lab's eye view of testing • Accuracy vs. cost	Daniel Yap *Food Service Technology Center*
2:15	Characterization of Effluent from Cooking Processes • CE-CERT baseline data • University of Minnesota / ASHRAE study	Bill Welch *UC Riverside, CE-CERT* Don Fisher *Food Service Technology Center*
2:45	Break	
3:00	When is a hood required?	Don Fisher *Food Service Technology Center*
3:15	Emission Control Devices • Particle size vs. control strategies • Control device efficiencies • Process change implications	Bill Welch *UC Riverside, CE-CERT*
3:45	Real-World Experiences with Restaurant Exhaust and Odor Control	Richard Charles *Charles & Braun Consulting Engineers* Don Fisher *Food Service Technology Center*
4:45	Industry Panel - Open Discussion	
5:00	Adjourn	


Commercial Cooking Equipment:
Practical Limits in
Emission and Odor Control
Don Fisher
Fisher-Nickel Inc.
PG&E
Food Service
Technology Center
Co-Sponsored by the California Energy Commission


How much is too much?
Can it be measured?
Does it contribute to smog?
Can it be controlled?

The Answers and More…….

- Update on California legislation
- Lab view of measurement protocols
- Characteristics of cooking emissions
- Critical assessment of control options
- A look to the future
- Real-world experiences with wood-fired cooking equipment

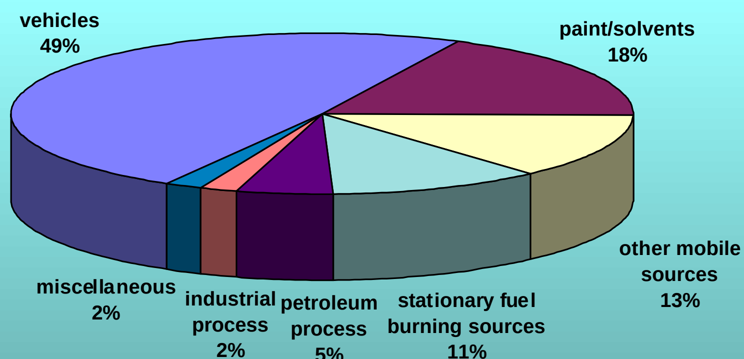
Side Bars…...

- Grease removal at the hood - filter efficiencies
- When is a hood not required?
- Ductless hoods: IAQ implications
- Odor problems may be harder to get rid of than prevent!
- Importance of stack design
- Real limits to cost-effective control!

L.A. Basin - Smog City!

Regulated by the South Coast Air Quality Management District (SCAQMD)

Sources of Pollution



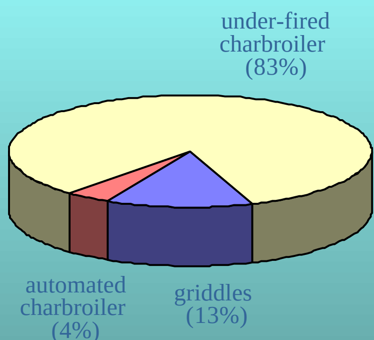
SCAQMD estimates over half due to commercial cooking

EPA/AQMD Targets:

- Particulate Matter (PM)
  - smoke and grease particles
  - 10 microns or less (< 0.00000001 m)
  - includes condensable grease vapor
- Volatile Organic Compounds (VOC)
  - hydrocarbon (C-H)
  - carbonyl (C=O)

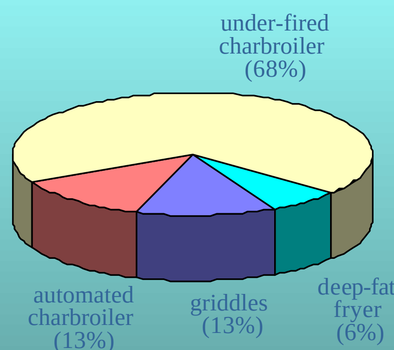
Contribution by Appliance Type

Particulate Matter (PM)



deep-fat fryer PM emissions negligible

Volatile Organic Gases (VOC)



Emission Control Challenge

- Grease!
- Diversity in cooking processes
- Cost of measurement
- Performance of control devices
- Cost of control equipment
- Lack of “hard” data!
- Human perceptions!

Control Strategies

- Catalytic conversion
- Electrostatic precipitator (ESP)
- Filtration
- Scrubbers
- Absorption/Adsorption
- After burner
- Odor masking
- Process change

Installed Cost:	$10,000 - $250,000
Maintenance/utility cost:	$$$$
Performance:	??????

SCAQMD's Rule 1138

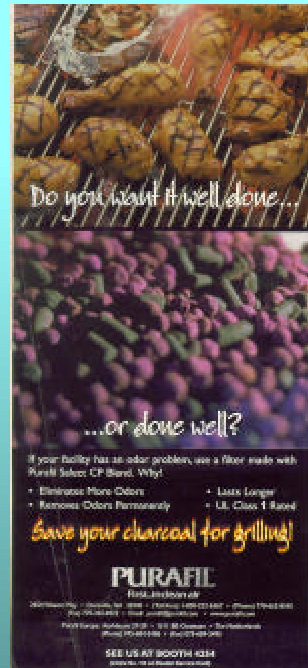
- Requirement
  - All chain-driven, automated charbroilers must operate with a catalytic control device
- Exemption
  - Exemption permit will be issued to those cooking less than 875 lb of meat per week.
  - Demonstrate emissions from the automated charbroiler is less than 1 lb/day

SCAQMD's Plans

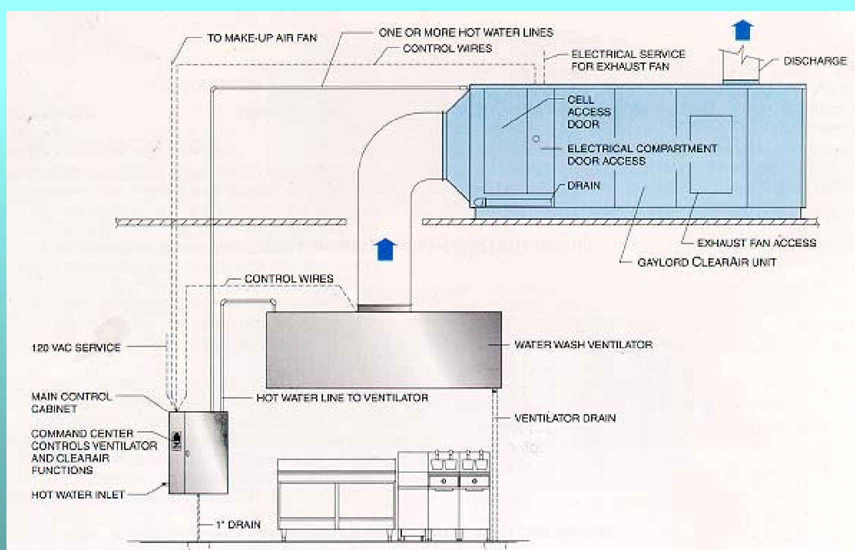
- Pursue cost effective control technologies for under-fired charbroiler.
- Modify Rule 1138 to include under-fired charbroilers
- Probably a year or two away.

Rule 1138 on-line at the AQMD's homepage
http://www.aqmd.gov/rules/html/r1138.html

State-of-the-Ad

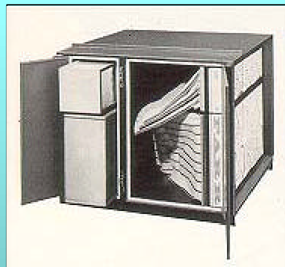


Classic Control



System Components

3. Odor Control Module

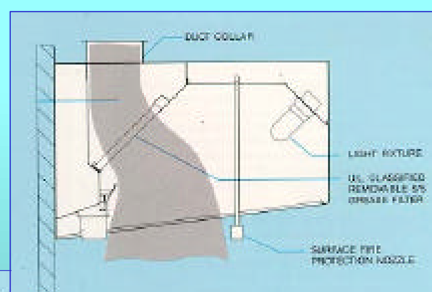


2. ESP or Filter Module

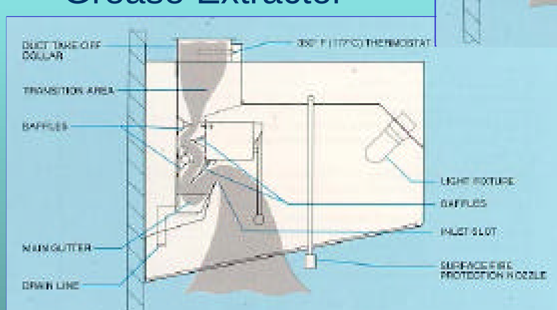
1. Hood Filter and/or Water Spray

Filter Efficiencies

Much less than you think!



Grease Extractor



Baffle Filter

Hood filters cannot remove grease vapor, and vapor may be a major component of the effluent. But vapor does condense!

The Future?

- Better understanding of the “problem” and the “solution”
- Need data for wood-fired equipment
- New generation of control equipment
- Expanded restaurant AQMD legislation in cities across North America

because………...

San Francisco Smogline!

APPENDIX VI

SCAQMD Rule 1138, Control of Emissions from Restaurant Operations

(Adopted November 14, 1997)

RULE 1138. CONTROL OF EMISSIONS FROM RESTAURANT OPERATIONS

(a) Applicability

This rule applies to owners and operators of commercial cooking operations, preparing food for human consumption. The rule requirements currently apply to chain-driven charbroilers used to cook meat. All other commercial restaurant-cooking equipment including, but not limited to, under-fired charbroilers, may be subject to future rule provisions.

(b) Definitions

1. CATALYTIC OXIDIZER means a control device which burns or oxidizes smoke and gases from the cooking process to carbon dioxide and water, using an infrastructure coated with a noble metal alloy.
2. CHAIN-DRIVEN CHARBROILER is a semi-enclosed cooking device with a mechanical chain which automatically moves food through the device and consists of three main components: a grill, a high temperature radiant surface, and a heat source.
3. CHARBROILER means a cooking device composed of the following three major components: a grated grill, a high-temperature radiant surface and a heat source. The heat source heats the high-temperature radiant surface, which provides the heat to cook the food resting on the grated grill. This includes, but is not limited to broilers: grill charbroilers, flamebroilers and direct-fired barbecues.
4. EXISTING CHAIN-DRIVEN CHARBROILER means any chain-driven charbroiler operating on or before November 14, 1997.
5. MEAT, for the purposes of this rule, includes beef, lamb, pork, poultry, fish, and seafood.
6. NEW CHAIN-DRIVEN CHARBROILER means any chain-driven charbroiler initially installed and operated after November 14, 1997.
7. RESTAURANT means any stationary commercial cooking establishment which prepares food for human consumption.
8. UNDER-FIRED CHARBROILER means a cooking device which has a grill, a high temperature radiant surface, and a heat source which is located below the food.
9. WEEKLY means a consecutive seven-day period.

(c) Requirements

1. No person shall operate an existing chain-driven charbroiler on and after November 14, 1999 unless it is equipped and operated with a catalytic oxidizer control device, and the combination charbroiler/catalyst has been tested in accordance with the test method specified in subdivision (g) and certified by the Executive Officer. Other control devices or methods may be used, if found, in accordance with the test method specified in subdivision (g), to be as or more effective than the catalytic oxidizer in reducing particulate matter (PM) and volatile organic compounds (VOC) (as defined in Rule 102) emissions and certified by the Executive Officer.
2. Notwithstanding provisions of paragraph (c)(1) of this rule, persons operating an existing chain-driven charbroiler with permitted control equipment may elect to maintain that equipment for the duration of its functional life not to exceed 10 years from November 14, 1997. At such time, such persons may elect to either replace the existing control equipment with a catalytic oxidizer control

device which in combination with the chain-driven charbroiler has been tested in accordance with the test method specified in subdivision (g) and certified by the Executive Officer, or other control device or method found to be as or more effective than the catalytic oxidizer in reducing PM and VOC emissions in accordance with the test method specified in subdivision (g) and certified by the Executive Officer.

3. No person shall operate a new chain-driven charbroiler after November 14, 1997 unless it is equipped and operated with a catalytic oxidizer control device, and this combination charbroiler/catalyst has been tested in accordance with the test method specified in subdivision (g) and certified by the Executive Officer, or other control device or method if found to be as or more effective than the catalytic oxidizer in reducing PM and VOC emissions in accordance with the test protocol specified in subdivision (g) and certified by the Executive Officer.

4. Catalytic oxidizers or other control devices shall be maintained in good working order to minimize visible emissions to the atmosphere, and operated, cleaned, and maintained in accordance with the manufacturer's specifications in a maintenance manual or other written materials supplied by the manufacturer or distributor of the catalyst or other control device, or chain-driven charbroiler.

(d) Recordkeeping

1. Owners and operators of chain-driven charbroilers equipped with control equipment shall, at the time of occurrences listed in subparagraphs (d)(1)(A) and (B), record such actions and retain the records for a period of not less than five years. These records shall be made available to a District representative upon request. Records shall consist of:

   (A) the date of installation or changing of any catalyst or, if applicable, other certified control device; and

   (B) the date and time of cleaning and maintenance performed for the catalyst or, if applicable, other certified control device.

2. Owners and operators of chain-driven charbroilers operating under an exemption from provisions of this rule pursuant to subdivision (e), shall maintain weekly records of the amount of meat cooked and monthly records of the amount of meat purchased. These records shall be retained on the restaurant premises for a period of not less than five years and made available to a District representative upon request.

3. Persons may request use of alternative recordkeeping, provided the Executive Officer and EPA have determined, in writing, that the alternative recordkeeping method provides equivalent compliance assurance as the records specified in paragraphs (d)(1) or (d)(2).

(e) Exemption

An owner or operator of a chain-driven charbroiler may apply for an exemption from provisions of paragraphs (c)(1) through (c)(4) and (d)(1):

1. based on accepting a permit condition limiting the amount of meat cooked on the chain-driven charbroiler to less than 875 pounds per week; or

2. by supplying evidence from testing pursuant to the test method specified in subdivision (g), demonstrating that emissions from the chain-driven charbroiler are less than the one pound per day of any criteria air contaminant, and accepting permit conditions necessary to preclude an exceedance of that level of emissions.

(f) Evaluations

The Executive Officer will evaluate Rule 1138 and report to the Governing Board, no later than 18 months from the date of its adoption, to assess the feasibility of emission reductions and whether cost-effective control devices or other methods are available for the control of emissions from under-fired charbroilers and potentially other commercial restaurant cooking equipment.

(g) Test Methods

The District's Protocol - Determination of Particulate and Volatile Organic Compound Emissions from Restaurant Operations shall be used to determine the pounds of PM and VOC per 1,000 pounds of meat cooked.

APPENDIX VII

Commercial Kitchen Ventilation Seminar Flyer and Agenda

FOOD SERVICE TECHNOLOGY CENTER

INVITES YOU TO A

COMMERCIAL KITCHEN VENTILATION SEMINAR

PG&E's Food Service Technology Center has been dedicated to establishing comprehensive performance test methods for benchmarking equipment used in commercial kitchens. The leader in independent commercial appliance testing, PG&E measures energy consumption of gas and electric appliances under both laboratory and real-world conditions. Directly related to the performance and energy efficiency of commercial cooking equipment is the associated exhaust ventilation system. However, commercial kitchen ventilation systems are typically designed, installed and operated with little consideration for energy efficiency. The lack of comprehensive design information available for commercial kitchens has generated controversy throughout the engineering community. Food service consultants, design engineers, food service owner / operators and building inspectors should attend to learn how to design and operate more energy efficient systems. The seminar will focus on:

Energy intensity of HVAC systems,

Dispelling kitchen ventilation myths,

Optimizing design strategies,

New software for calculating outdoor air loads,

Reducing kitchen ventilation energy costs,

ASHRAE, SCAQMD updates, and much more!

WHEN:
MONDAY, SEPTEMBER 28TH
8:45 A.M. - 3:00 P.M.

WHERE:
PG&E ENERGY CENTER
851 HOWARD STREET

(Between 4th and 5th Streets)
San Francisco, CA
415-973-7268

Commercial Kitchen Ventilation Seminar Agenda

Monday, September 28th

8:45	Continental Breakfast
9:15	HVAC in Commercial Food Service — *An Energy Perspective*
9:45	ASHRAE's role in the commercial kitchen
10:15	Kitchen Exhaust Ventilation - *Cut the Hot Air!*
10:45	Break
11:00	Kitchen Exhaust Ventilation - *Optimized System Design*
11:30	*Kitchen Ventilation Energy Costs* - New software for calculating outdoor air loads
12:00	Lunch
1:00	*Emissions From Commercial Cooking* - New legislation in California drives R&D in kitchen ventilation
1:30	*Cashing in on Experience* — An industry panel discusses real-world design practice
2:00	Tour the PG&E Energy Center
3:00	Adjourn

✠✠

To register, please contact Cathy Cesio at 925-866-5706, e-mail: CACZ@pge.com or fax this form to 925-866-2864. Cost: $45 / person

Name: ____________________

Title: ____________________

Company: ____________________

Mailing Address: ____________________

____

Phone: ____________________

Please make check out to:

PG&E Food Service Technology Center
12949 Alcosta Blvd., suite 101
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PG&E Food Service Technology Center

Commercial Kitchen Ventilation Seminar WWW.PGE.COM/FSTC

Monday, September 28, 1998

8:45	Continental Breakfast	
9:00	Welcome and Introduction	Richard Young *Food Service Technology Center*
9:15	HVAC in Commercial Food Service — *An Energy Perspective*	Don Fisher *Food Service Technology Center*
9:45	ASHRAE's role in the commercial kitchen • A new handbook chapter on kitchen ventilation • Development of a new Standard for Ventilation of Commercial Cooking Operations	Don Fisher *Food Service Technology Center*
9:45	Kitchen Exhaust Ventilation – *Cut the Hot Air!* • Perspectives on system design • Sizing hoods for the equipment below • Gas versus electric equipment – is there a difference? • The short circuit hood – science or fiction?	Don Fisher *Food Service Technology Center*
10:45	Break	
11:00	Kitchen exhaust Ventilation – *Optimized System Design* • New Schlieren flow visualization technique • Role of laboratory testing • Future of variable speed systems	Rich Swierczyna *Architectural Energy Corporation*
11:30	Estimating Kitchen Ventilation Energy Costs • New software for outdoor air loads and fan energy	Don Fisher *Food Service Technology Center*
12:00	Lunch	
1:00	Emissions From Commercial Cooking • New legislation in Southern California	Daniel Yap *Food Service Technology Center*

1:30	Cashing in on Experience	Industry Panel
2:00	Tour of the PG&E Energy Center	
3:00	Adjourn	

APPENDIX VIII

Commercial Kitchen Ventilation Guideline for California

GUIDELINES FOR OPTIMIZING DESIGN AND OPERATION OF COMMERCIAL KITCHEN VENTILATION SYSTEMS IN THE STATE OF CALIFORNIA

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Introduction

This guideline provides information about achieving and maintaining optimum performance and energy efficiency in commercial kitchen ventilation (CKV) systems. The objective of maximizing energy efficiency must be done in the context of maintaining the health and safety functions of the CKV system. The interaction of the CKV system with all of the energy producing systems in the kitchen, such as hooded and unhooded appliances, the exhaust hood and fans, makeup air introduction, as well as the space conditioning system, must be considered. The information presented is applicable to new construction and, in many instances, retrofit construction. The audience for this guideline is kitchen designers, mechanical engineers, food service operators, property managers, and maintenance people.

The importance of ventilation energy in food service facilities is addressed in the next section.

Energy Perspective

Food service establishments are the most intensive energy users in the commercial building sector.[1] Typical annual energy consumption for restaurant operations was reported at 550 kBtu/ft^2 compared with 100 kBtu/ft^2 for other commercial sub-sectors (e.g., offices, retail, schools, lodging). The annual energy bill for the food service industry in the U.S. is estimated at $12 billion.

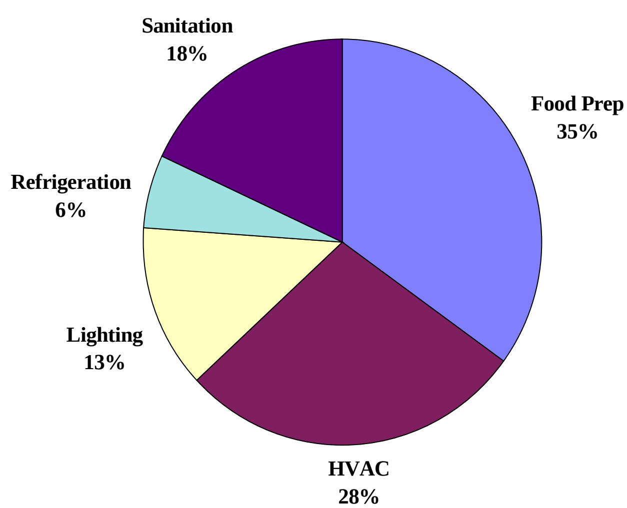

Figure 1. Representative Breakdown Of Energy End-Use In A Food Service Operation.

Commercial kitchen ventilation (CKV) systems have a significant impact on the energy consumption of food service facilities. It has been demonstrated[2] that the HVAC load represents approximately 30% of the total energy consumed in a restaurant (Figure 1). It has been further estimated[3] that the kitchen ventilation system can account for up to 75% of the HVAC load, and as such, may represent the largest single-system energy consumer in food service operations. However, commercial kitchen ventilation systems are typically designed, installed and operated with little consideration for energy efficiency. This can be attributed to the fact that designers are primarily concerned with the capability of the CKV systems to capture, contain and remove cooking contaminants, while the building owner's goal is to minimize both the design and installed cost of the HVAC system. The exhaust hood does not have an energy meter!

The problem is compounded by the lack of comprehensive design information for commercial kitchens. Although the ASHRAE handbooks are recognized as a fundamental source of information for designing HVAC systems, the handbooks prior to 1995 lacked design information for ventilating commercial cooking equipment. Thus, many designers have specified exhaust ventilation rates based on the more prescriptive code requirements or past experience. Not that kitchen exhaust systems designed according to "code" or "experience" are necessarily inadequate from the perspective of removing grease, odors and heat from the commercial kitchen—the general concern with respect to energy conservation is the "safety factor" that has been built into the existing codes and design guidelines.

Conservation Potential

Although the opportunities for energy conservation and load management in CKV are large, the lack of publicly documented lab and field data has made achieving savings difficult. Based on a survey of CKV equipment manufacturers[4] and recently published data, total kitchen ventilation exhaust in the United States appears to be in the range of 2.5 to 3.0 billion cfm. Table 1 shows a summary by industry segment. Data published by Cahners Bureau of Foodservice Research shows that an estimated total of 737,000 food service facilities were in operation in 1992.[5] The California Restaurant Association estimates that there are about 71,000 food service units in California, or about 10% of the national total. The per unit exhaust volumes are estimates based on collective design experience and knowledge of installed systems by researchers.[6]

Table 4 Summary of Ventilation Volumes by Facility Type in the United States

Industry Segment	**Number of Units**	**Estimated Exhaust Per Unit (cfm/unit)**	**Total Exhaust (Million cfm)**
Fast Food	180,125	3,000	540
Full Service	196,250	6,000	1,177
Educational	92,460	3,500	319
Health Care	63,730	3,500	219
Grocery & Retail	106,425	600	67
Lodging, Rec.	64,875	4,300	281
Other	33,300	4,400	146
Grand Totals	**737,165**	**3,700**	**2,749**

Total estimated savings should average between 30% and 40%, with some facilities as high as 60%.[6] Results from computer modeling of fast food and full service facilities support this estimate as well.[7] Total cost savings across the industry could range from $1.0 to $1.5 billion per year. A reduction in CKV rates will:

- improve energy efficiency in restaurants,

- lower restaurant demands (often at system peak hours),
- reduce capital construction costs by decreasing the size of installed HVAC equipment, and
- have a positive impact on the environment by reducing utility loads at the source and reducing effluent discharged from CKV systems to the atmosphere.

For example, exhaust hood face velocities of 100 to 150 feet per minute (fpm) are dictated by code, but levels as low as 50 to 75 fpm have been shown to be satisfactory.[8] An experimental study[9] published by ASHRAE reported that for wall and island canopies, only 40 to 50% of the normal design flow was required to provide satisfactory capture of smoke generated at any location on or beside the cooking surfaces. These studies are consistent with research and development conducted by McDonald's Corporation.[10] In general, their laboratory-based hood design and sizing procedures have allowed McDonald's to install backshelf hoods that operate at exhaust ventilation rates that are significantly below code (e.g., 150 cfm/ft vs. 300 cfm/ft).

In addition to the energy/load management benefits that can be achieved through a direct cfm reduction in exhaust capacity, significant benefits can be realized through integrated HVAC design strategies, engineered equipment, and enhanced system control and operation. Optimizing systems and operating strategies for foodservice facilities during retrofit and new construction will present additional opportunities that will not be at the expense of customer or employee comfort.

8.1.1 Listed Hoods

It is important to recognize that a large percentage of the CKV systems being installed today are designed and operated below the code ventilation rates. Many of the commercially available exhaust hoods have been listed[11] by Underwriters Laboratories (UL) at air flow rates significantly below code (e.g., 300 cfm vs. 450 cfm per linear foot of hood for heavy duty cooking) and are typically permitted by the "authority having jurisdiction." The National Fire Protection Association's (NFPA) Standard 96 simply states that "Exhaust air volumes for hoods shall be of sufficient level to provide for the capture and removal of grease laden vapors."

An industry survey[4] indicated that 60 - 70% of the total installed base of kitchen hoods are UL listed hoods. Although there is general agreement within the industry that the exhaust rates dictated by code are excessive, there is no consensus regarding the potential for reduction in the design ventilation for UL listed hoods. In fact, several manufacturers have suggested that their UL values may not be adequate for many applications.

Figures 2A, 2B and 2C illustrate the range in exhaust volumes that could be specified to ventilate the same cooking appliance, reflecting the conservative position of the codes and the benefit of an engineered system.

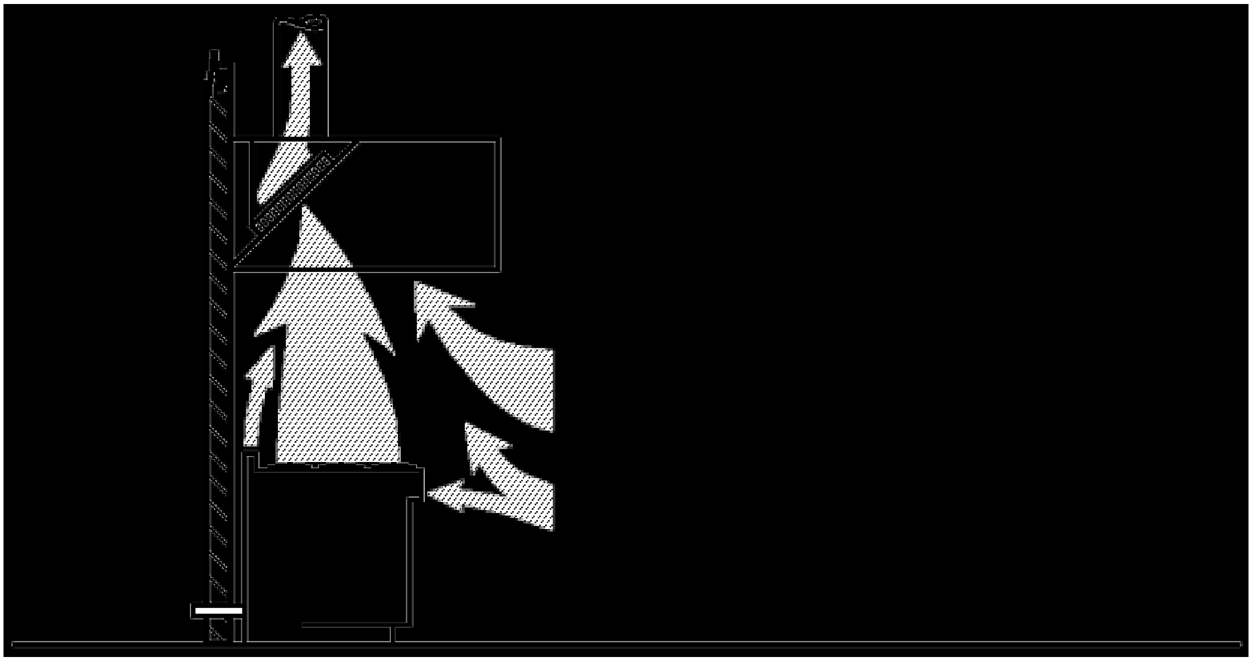

Figure 2(A) **Typical Code Requirement**

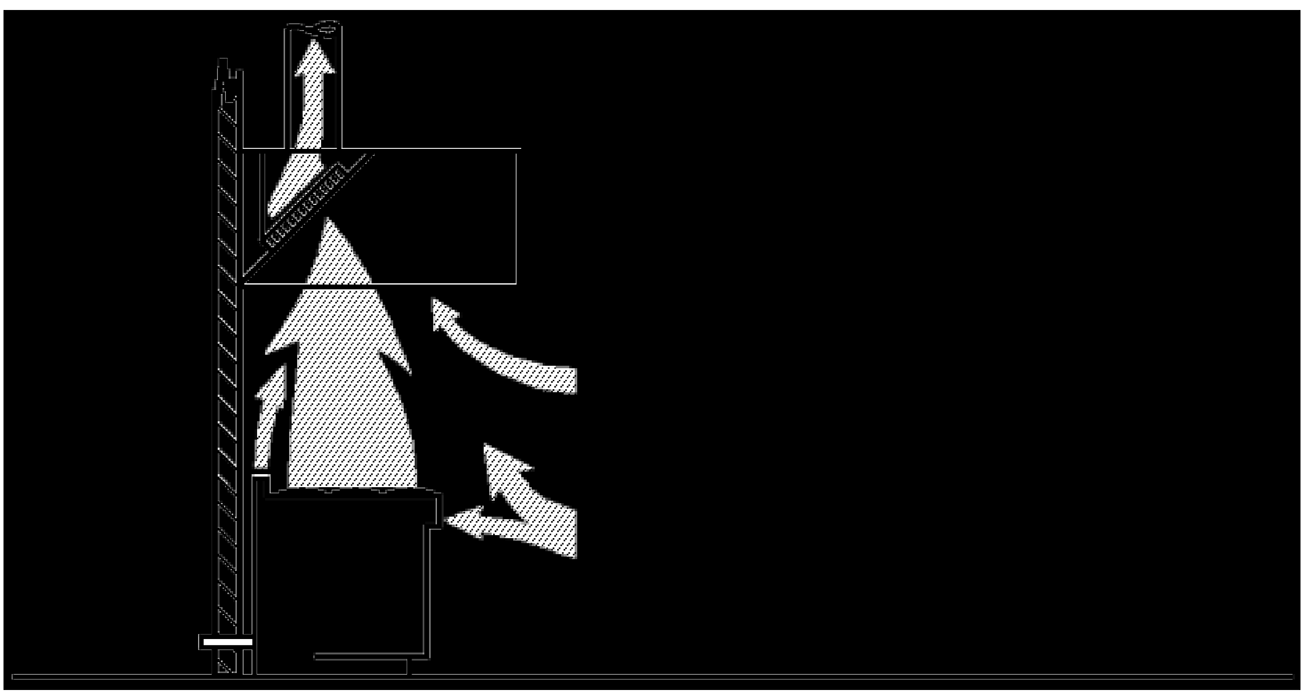

Figure 2(B) **Example UL Listed Hood**

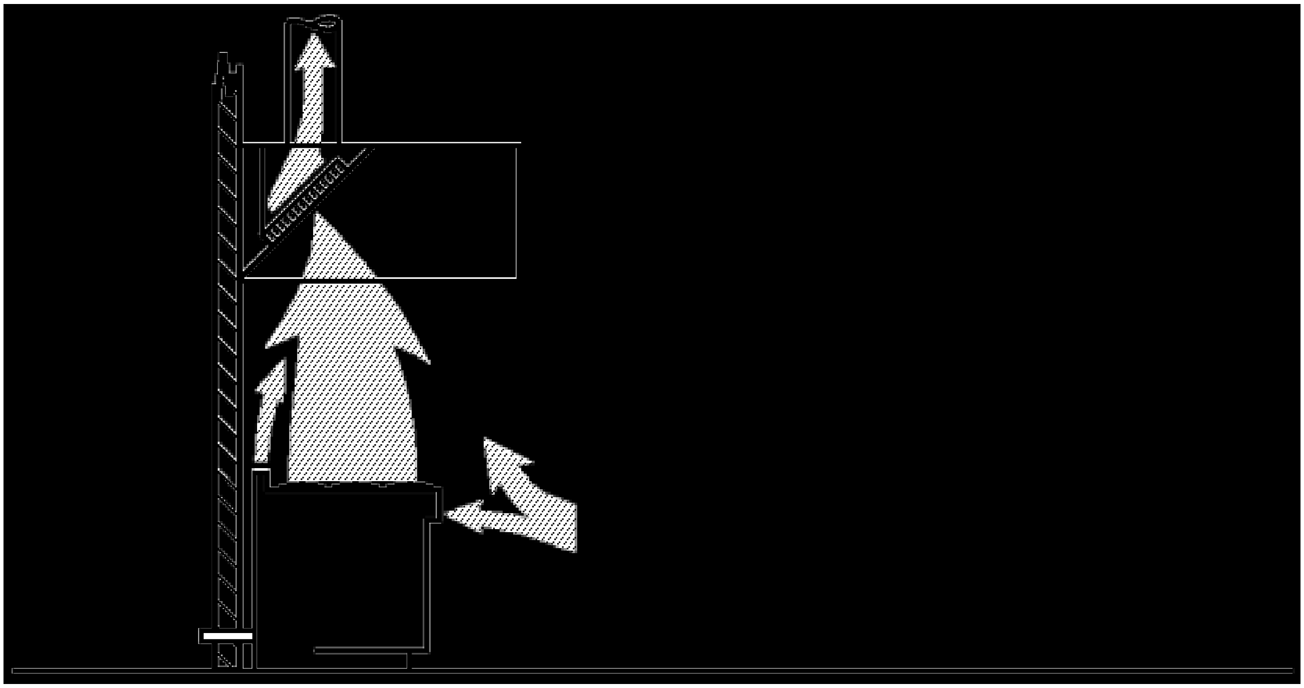

Figure 2(C) **Custom Hood (with Side Panels)**

Design Challenge

It is generally acknowledged that there are different ventilation requirements for the different types of appliances based on the quantity of heat and vapors produced by the cooking process. And that is where the agreement ends! There is significant controversy in the industry with regard to both the minimum ventilation requirements for specific equipment and the procedures used for the design of hood/appliance systems. The problem is compounded by the many variations in the design and operation of both exhaust hoods and cooking equipment.

Short-Circuit Hoods—A Solution?

A controversial issue relates to the performance of what are referred to as "short-circuit" exhaust hoods. Alternatively referred to as "compensating," "no-heat," or "cheater" hoods, these internal makeup air hoods were developed as a strategy to reduce the amount of conditioned air required by an exhaust system designed to code (Figure 3A). By introducing a portion of the required makeup air in an untempered condition directly into the exhaust hood itself, the net amount of conditioned air exhausted from the kitchen is reduced. Thus, the total exhaust capacity of the system will be able to meet prescriptive code requirements while the actual quantity of makeup air that needs to be heated or cooled is minimized. So if less "net" exhaust air is adequate, why not simply design the exhaust system to ventilate the cooking equipment at a reduced rate in the first place? A good idea, but the existing codes are often too rigid to accommodate this design strategy—and the specification of short-circuit hoods continues to be attractive. But if the amount of short-circuited air reduces the net ventilation to the point where spillage of cooking effluent occurs (Figure 3B), the kitchen environment may be compromised. The industry clearly needs more definitive research to qualify the application of internal makeup air hoods.

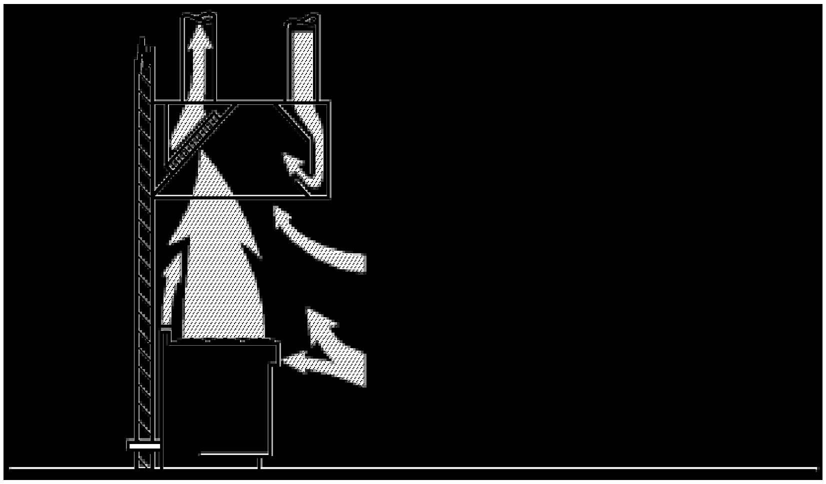

Figure 3(A) **Short-circuit hood operating with full containment**

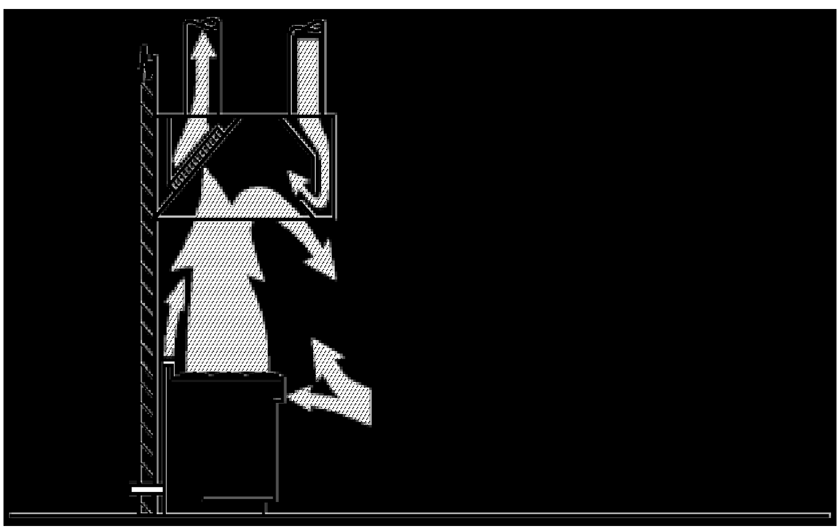

Figure 3(B) **Short-circuit hood with spillage**

Gas versus Electric

Another issue relates to the difference in the ventilation requirements for gas and electric cooking equipment. Although it is generally acknowledged that a higher exhaust ventilation rate may be required for gas appliances, the actual magnitude of ventilation air for combustion products has not been documented (Figures 4A & 4B). This has been a focus of recent CKV research.[12]

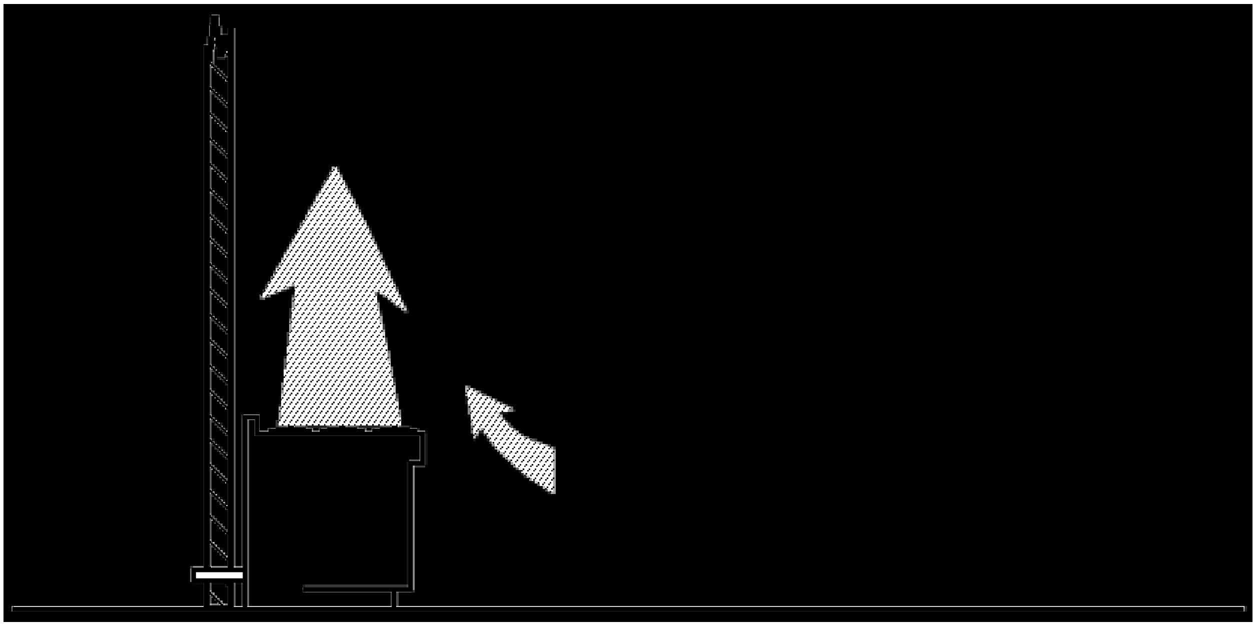

Figure 4(A) **Requirements for Electric Appliance Ventilation**

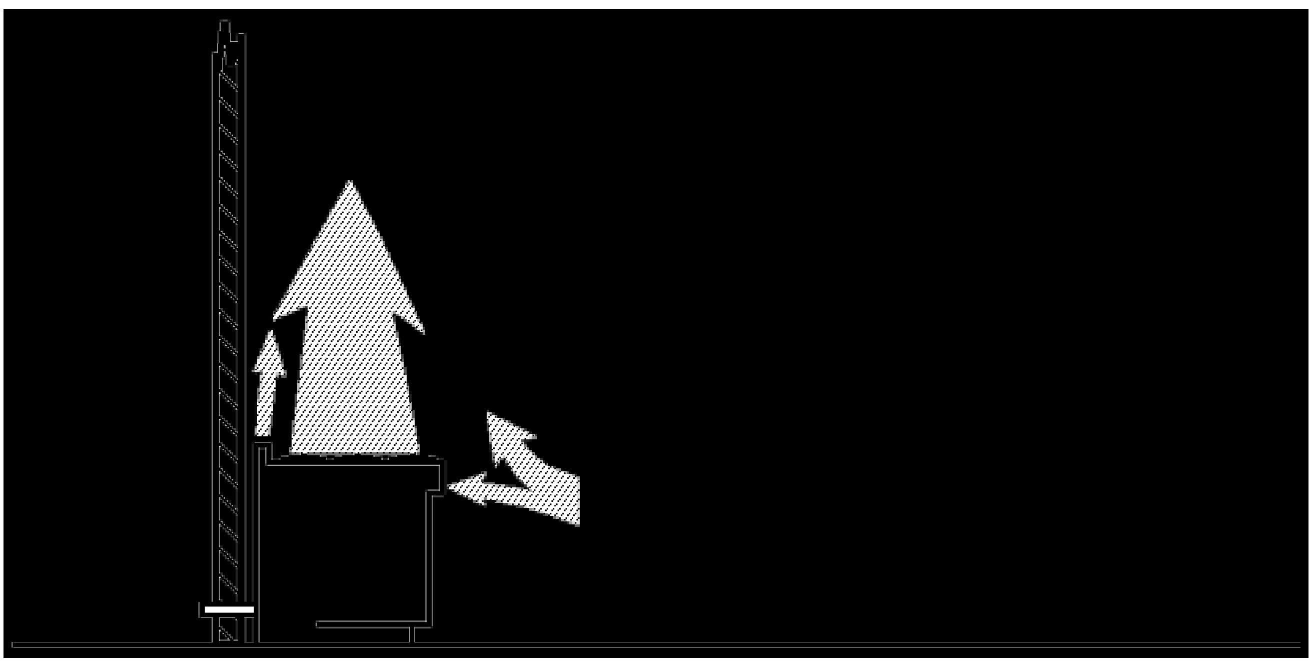

Figure 4(B) **Requirements for Gas Appliance Ventilation**

Need for Standardization

Design practices for kitchen ventilation systems have been influenced strongly by codes in the U.S. Codes such as the Uniform Mechanical Code, Uniform Building Code, and up to 1973, the National Fire Protection Association (NFPA Standard No. 96) have listed the required exhaust air quantities according to the type, placement and face area of the exhaust hood. Unfortunately, these design criteria were not based on actual performance evaluation of exhaust systems operating over different pieces (or groups) of operating cooking equipment. This prescriptive approach also has been adopted by the new International Mechanical Code (IMC).

A study[13] conducted by the National Conference of States on Building Codes and Standards under contract with the Electric Power Research Institute documented the lack of uniformity in the way kitchen exhaust system design criteria and codes are applied across the country. This study, titled an Assessment of Building Codes, Standards and Regulations Impacting Commercial Kitchen Design, revealed:

"*a lack of correlation between effluent characteristics and exhaust requirements. Codes generally treat all cooking processes identically, although different processes may produce such varying effluents as heat, grease, vapor, odors, steam, or smoke. In addition, state codes frequently differ in how they regulate cooking processes that produce the same effluents. In general, many code provisions have no clear technical documentation, and available technical studies indicate that code ventilation requirements often substantially exceed actual needs.*"

ASHRAE Focus

Technical issues and concerns related to kitchen ventilation have been discussed at ASHRAE forums, seminars, symposia and technical sessions for a number of years. "Standing room only" attendance has been the experience at these kitchen ventilation programs. Although several technical committees (TC's) have served as sponsors, the number of individuals on any TC with a major interest in kitchen ventilation has been limited, as is the scope of existing TC's with respect to this topic. In an effort to focus ASHRAE's effort in this area, and to meet a perceived need of its membership, an ASHRAE technical committee on kitchen ventilation (TC5.10) was finally established. The mission of this committee on kitchen ventilation is to address the needs of ASHRAE membership with respect to the energy efficient control, capture, and effective removal of airborne contaminants and heat resulting from the cooking processes. The technical scope includes the introduction of supply and makeup air as it influences the contaminant control process, and the thermal environment in the cooking space.

In 1995 this committee developed a new handbook chapter on kitchen ventilation[14], which is a good starting point for the designer of CKV systems. The chapter was updated in 1999. Unfortunately, there is still little guidance within the new handbook chapter with respect to the introduction of makeup air and the effect that a makeup air strategy will have on hood performance and/or energy consumption of the system—a priority of future ASHRAE research.

There has been strong industry support of ASHRAE's involvement in kitchen ventilation, and a new Standard Project Committee, designated SPC 154P, is currently developing a Standard for Ventilation of Commercial Cooking Operations. The focus of the proposed ASHRAE standard will be towards optimizing the design and operation of the commercial kitchen ventilating systems with respect to system performance (e.g., capture and containment). Ultimately, the goal of the ASHRAE standard is to impact standardization of the mechanical codes across North America.

A simplified schematic of the CKV standardization process from an ASHRAE perspective is illustrated in Figure 5, where the target conservation and load management goals are realized through the development of new design guidelines and supporting changes to codes.

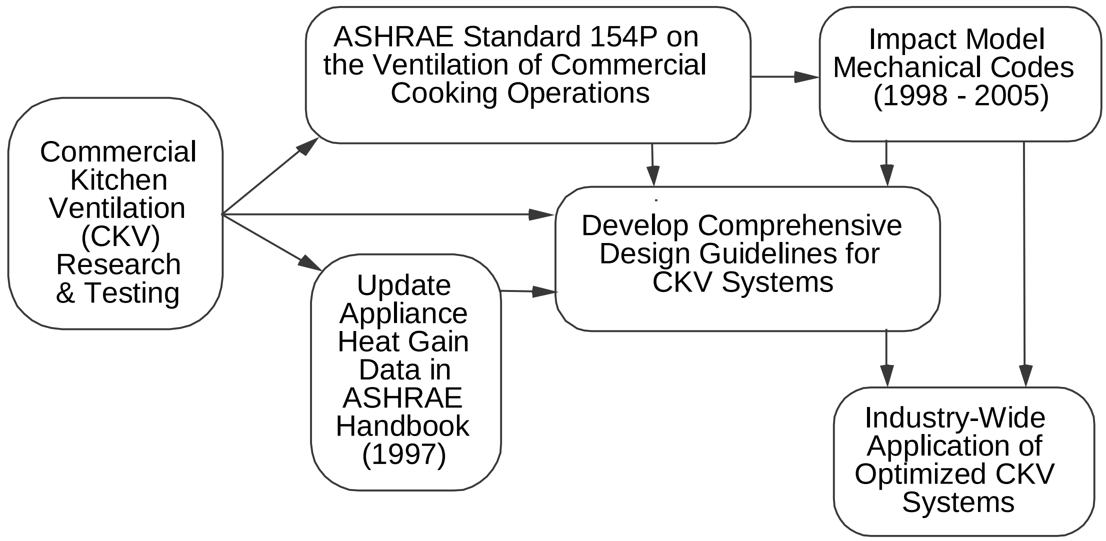

Figure 5 **Impact of CKV Research on Codes and Design**

CKV Research

In parallel with the cooking appliance research conducted by Pacific Gas and Electric Company at its Food Service Technology Center (FSTC), GRI and EPRI have funded separate commercial kitchen ventilation projects over the past several years. GRI's project was centered at the AGA Research Commercial Kitchen Ventilation Research Laboratory in Cleveland, Ohio. EPRI's Commercial Kitchen Ventilation Laboratory, formally the McDonald's Corporation Air Lab, is in Wood Dale, Illinois. In 1994 these two programs collaborated in a round of inter-lab testing to validate the standard test method that became ASTM F 1704-96, *Standard Test Method for Performance of Commercial Kitchen Ventilation Systems*.[15] Pacific Gas and Electric Company's FSTC coordinated the integration of research results from the two projects and the inclusion of new heat gain data in the ASHRAE Handbook of Fundamentals, 1997 Edition.[16]

Industry deregulation in recent years has shifted research priorities for both GRI and EPRI. One impact of the shift is that CKV research is no longer a high priority for either GRI or EPRI. As part of its commitment to food service research, Pacific Gas and Electric Company took over funding the EPRI CKV Lab in 1999 and has recently started a major CEC-sponsored research project on the influence of makeup air sources on capture and containment. In addition to funding the CKV Lab in Illinois, Pacific Gas and Electric Companyis currently completing the build-out of a CKV test facility at its Food Service Technology Center in San Ramon, California.

The EPRI CKV Lab has applied a focusing schlieren flow visualization system to assess the capture and containment performance of hoods and appliances for the past three years. The schlieren flow visualization system is a major breakthrough for visualizing thermal and effluent plumes from hot and cold processes, particularly in food service. The word "schlieren" means "smear" in German; the optical effect encompassed by the word is best illustrated by the wavy visual pattern that can be seen in the exhaust stream of jet aircraft or over a hot asphalt parking lot during the summer. The system at the CKV Lab is sensitive enough to detect the warm air coming off a person's body.

The schlieren flow visualization system allows non-intrusive investigation of hot air flow in real-time based on the refractive index dependency of air on temperature. Air in and surrounding the thermal plume from a cooking appliance changes its mass density and thereby its dielectric constant with temperature. This change in dielectric constant results in a change in refractive index, causing schlieren effect. The system at the CKV lab is capable of detecting a temperature difference of 5 °F per inch (0.11 °C per mm). Figure 6 shows still photos of some test results. However, one of the real advantages of this flow visualization technique is the ability to document the dynamic flow patterns on video tape. It is predicated that this ground-breaking application of the schlieren flow visualization to kitchen exhaust hoods will revolutionize HVAC air-distribution research.

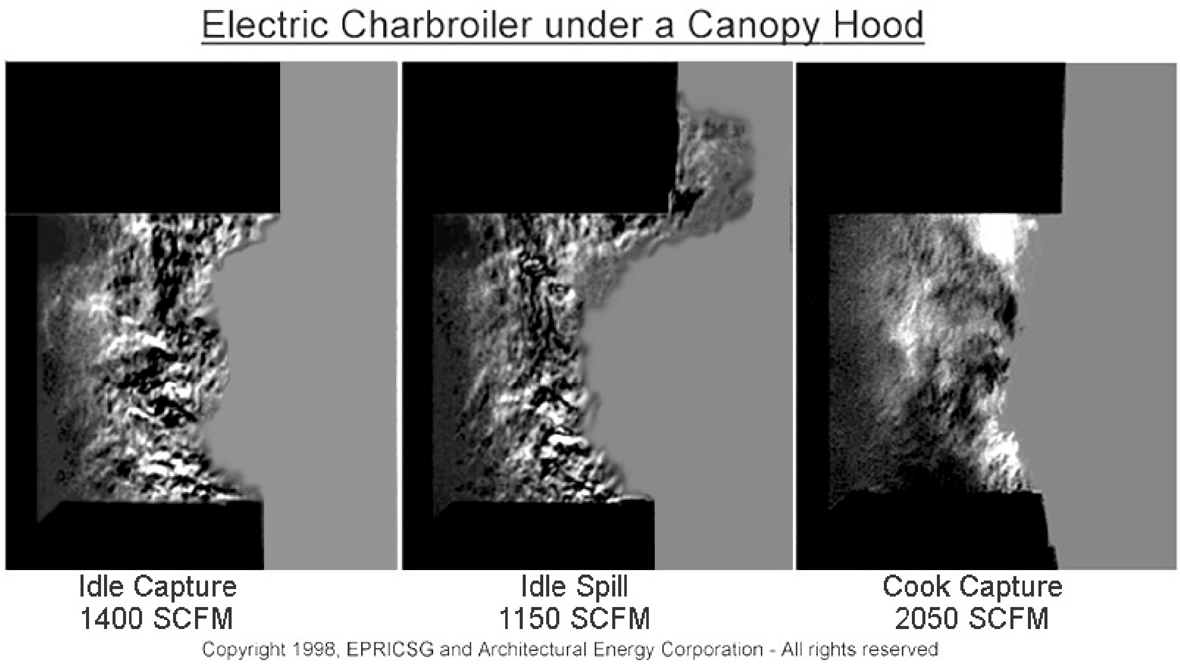

Figure 6 **Schlieren documentation of a clear, hot air plume (left two photos) and cooking plume (right side photo), with ideal (independent) makeup air delivery**

Figure 7 presents thresholds of capture and containment (C&C) for different types of gas and electric cooking appliances. These values were determined using such flow visualization techniques in accordance with the new ASTM test method.[15] Each appliance was individually operating under a 5-foot (wide) by 4-foot (deep) wall mounted canopy hood. Makeup air for this exhaust-only hood configuration was supplied in non-obtrusive fashion from the far side of the laboratory. The C&C threshold flow rate was determined for a heavy-load cooking condition and under an appliance “idle” or standby condition as reported by the EPRI lab in a recent ASHRAE paper.[12] As illustrated, there are significant differences between appliance types. In some cases, there are notable differences between fuel source and/or appliance usage (e.g., idle vs. cooking).

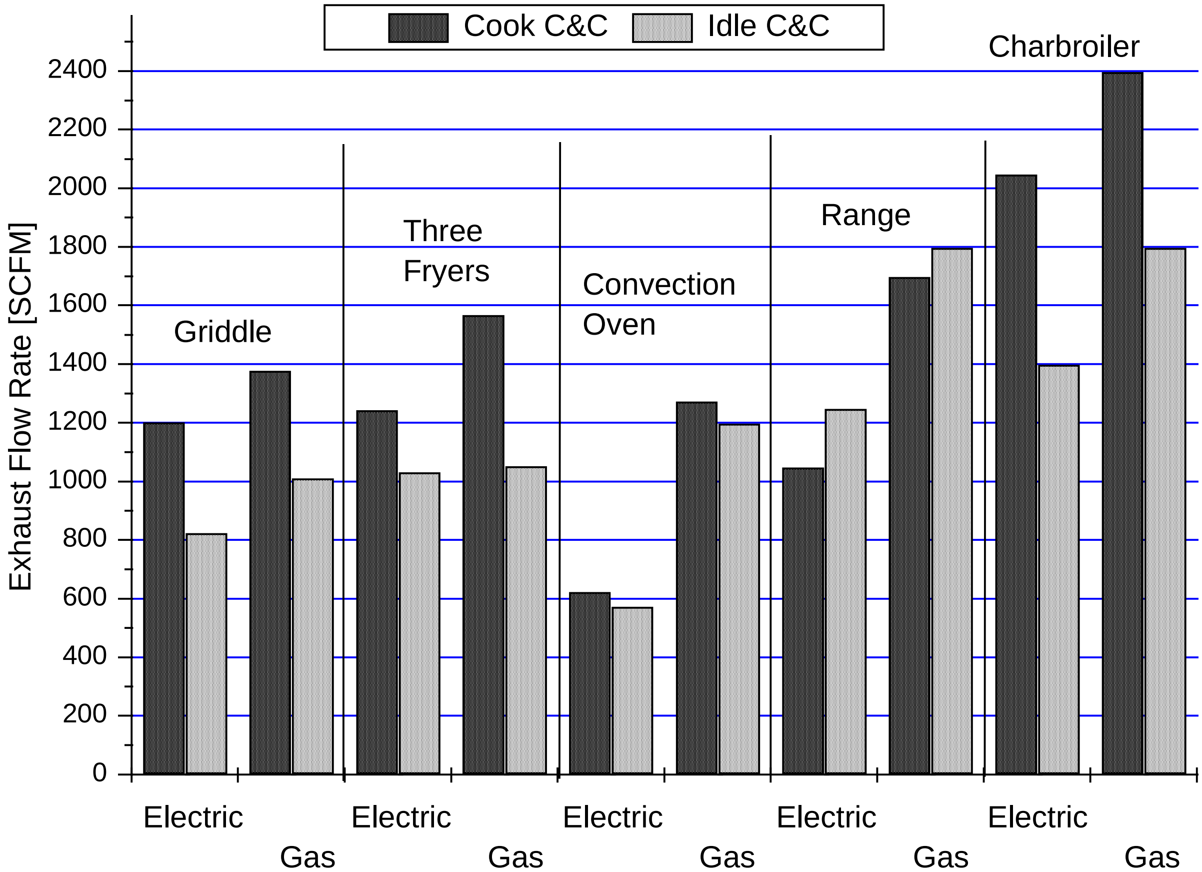

Figure 7 **Thresholds of Capture & Containment for a 5-ft Wall-Canopy Hood**[12]

Calculating Savings with the Outdoor Airload Calculator Software

The need for an easy-to-use tool that would accurately determine the heating and cooling load for a given amount of outdoor (makeup) air led to the development of the Outdoor Airload Calculator software (OAC). Since this tool does not model a complete building in detail, the minimal required input parameters are only geographic location, outdoor air flow, operating hours, and the heating and cooling set points. With these basic inputs, the OAC is able to calculate monthly and annual heating and cooling loads as well as design loads (the maximum heating and cooling load that occurred during the year). Through a “Details” menu it is possible to further customize the calculation setup for dehumidification and also equipment lockout during parts of the year.

The OAC is a component of a commercial cooking appliance energy-use model being developed by Pacific Gas and Electric Company in support of its food service customers. It is available as freeware over the World Wide Web at http://www.archenergy.com/AECHome/ckv/oac/default.htm. The only system requirement is a web browser that supports Java 1.1. This architecture makes the OAC available to users on many computing platforms, from large UNIX based systems over Macintosh compatible computers to Windows based PCs.

The OAC uses weather data in 4-hour bins for the calculation of heating and cooling loads. Weather data is currently available for 239 US locations, 47 locations in Canada, and 16 general climate zones in California. The individual weather data files contain dry bulb temperature and relative humidity with a time and date stamp.

The US weather files were created from TMY2 data files, which were provided by the National Renewable Energy Laboratory (NREL). TMY2 data files represent a typical meteorological year in hourly format. For increased space efficiency, while maintaining reasonable accuracy, the hourly weather data was reduced to 4-hour bin data through averaging. That way the annual weather data, consisting of 8760 hourly readings, gets reduced to 2190 data points. The 4-hour bin data makes the output heating and cooling load sensitive to the time-of-day that a ventilation system is operating.

The Outdoor Airload Calculator offers two reporting formats: (1) a text window contains printed text output with all simulation details and results, and (2) a spreadsheet-like table for comparative simulations. The text window report is especially useful to end users because of its readability. Restaurant and building operators can perform a simple and quick analysis of their facility while browsing the Internet. For comparative simulations the OAC offers a table output screen. This spreadsheet like table is useful to quickly determine the savings potential of various equipment settings and operations schedules. Both report forms can be transferred into other computer applications for further analysis.

Table 2 shows the results of calculations using the OAC software for the 16 California Climate Zones. The loads are calculated based on 1,000 cfm, 7 days per week for 52 weeks, 14 operating hours (8 AM to 10 PM), with the heating set point at 65°F and the cooling set point at 75°F. The OAC calculates the loads, but does not estimate purchased energy. To estimate purchased energy for the purposes of this example, the heating furnace efficiency was assumed to be 75%, and the compressor coefficient of expansion (COP) was assumed to be 2.0. For the example, average fuel costs are assumed to be $0.55 per Therm and $0.10 per kWh (including demand costs).

Table 5 Heating and Cooling Loads and Estimated Costs for 1,000 cfm

CA Climate Zone #	Elev.	Heating Load	Cooling Load	Heating Furnace Consumption	Compressor Load	Compressor Consumption	Supply Fan	Exhaust Fan	Gas Cost	Electric Cost	Total Cost
	ft	MBtu	MBtu	MBtu	MBtu	kWh	kWh	kWh	$0.55/ Therm	$0.10/ kWh	$
1	43	51.6	0.0	68.8	0.0005	0	702	1207	$ 379	$ 191	$ 569
2	164	37.5	7.9	49.9	3.964	1162	699	1202	$ 275	$ 306	$ 581
3	7	31.8	1.0	42.4	0.5145	151	703	1209	$ 233	$ 206	$ 439
4	98	27.6	4.2	36.8	2.075	608	701	1205	$ 202	$ 251	$ 454
5	236	27.9	1.1	37.2	0.5725	168	697	1199	$ 204	$ 206	$ 411
6	98	17.4	1.1	23.2	0.551	161	701	1205	$ 128	$ 207	$ 334
7	13	13.6	2.1	18.2	1.0535	309	703	1208	$ 100	$ 222	$ 322
8	384	16.3	6.6	21.7	3.2895	964	694	1192	$ 120	$ 285	$ 405
9	656	14.0	11.2	18.6	5.618	1647	687	1180	$ 102	$ 351	$ 454
10	1542	17.2	16.4	22.9	8.1925	2401	665	1143	$ 126	$ 421	$ 547
11	341	34.0	17.4	45.3	8.7155	2555	695	1194	$ 249	$ 444	$ 693
12	16	33.3	12.1	44.4	6.0655	1778	703	1208	$ 244	$ 369	$ 613
13	328	26.6	23.6	35.4	11.8	3459	695	1195	$ 195	$ 535	$ 730
14	2293	30.9	20.7	41.2	10.3575	3036	647	1112	$ 227	$ 479	$ 706
15	-30	8.3	50.9	11.0	25.4305	7454	704	1210	$ 61	$ 937	$ 997
16	3543	63.9	4.1	85.1	2.054	602	618	1061	$ 468	$ 228	$ 696

* Mbtu = 1,000,000 Btu

Optimization Strategies

Although the above discussion foreshadows the need for much future research, there is much that a building owner or manager can do today to realize CKV energy savings within a food service operation—particularly when upgrading existing or constructing new facilities. Using the new ASHRAE handbook chapter on kitchen ventilation[14] as a reference point, adopt a design strategy that will capitalize on today's knowledge—not yesterday's myths. *Encourage communication between the food service manager, the kitchen consultant, the mechanical engineer and the technical representative for the hood manufacturer*.

Consider the following system options or enhancements at the beginning of the design process—not the end:

- Group cooking equipment according to effluent production and associated ventilation requirements (i.e., an underfired broiler will require significantly more ventilation that a convection oven, 400 cfm/ft vs. 150 cfm/ft). Rely on a consensus between the hood manufacturer and the mechanical engineer to minimize the ventilation rate for the different categories of equipment and hood type specified.

- Install side curtains and/or back panels on canopy hoods to further increase their effectiveness and reduce heat gain to the kitchen. Consider integrated appliance/hood combinations.

- Use hoods with baffle filters (not water-wash hoods) over cooking equipment that produces little or no grease (e.g., compartment steamers, steam kettles, bake ovens).

- Integrate the kitchen ventilation with the building HVAC system (e.g., use dining room air as makeup air for the kitchen where feasible).

- Use makeup air temperature control that will capitalize on "free" cooling (e.g., California Climate Zones 1 – 9).

- In dry, warm climates (e.g., California Climate Zones 12 – 15) consider evaporative cooling for makeup air.

- In cold climates (e.g., California Climate Zone 16) evaluate the potential for exhaust air heat recovery. Be aware, however, that an air-to-air heat exchanger installed in a kitchen exhaust duct will require an automatic washdown system to remove grease on a daily basis.

- Incorporate makeup air temperature control that is responsive to space conditions (e.g., use a thermostat in the kitchen instead of one in the supply duct to control makeup air heating).

- Consider makeup air introduction strategies/locations that can offset appliance heat gains to the kitchen and further minimize makeup air heating requirements. Deliver makeup air so that it does not impede capture and containment of cooking effluent.

- Use multi-speed or variable volume fan control to reduce exhaust ventilation when appliances are turned on but not cooking food. Be advised, however, that NFPA 96 requires a minimum air velocity of 1500 ft/min. when grease producing appliances are cooking food. This lower limit on duct velocity still presents a hurdle to reducing exhaust ventilation rates in existing facilities.

- From an operational perspective, minimize the operating time of the kitchen ventilation system. Ensure that the exhaust and makeup air fans are turned off along with the cooking appliances. Fan energy is a significant component of a CKV system operating cost—particularly in California.

End Notes

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